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**NAVAL
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MONTEREY, CALIFORNIA

THESIS

**FORMULATING A STRATEGIC RESPONSE PLAN FOR
A HIGH-RISK SEISMIC EVENT IN NEW YORK CITY**

by

Michael B. Barvels

March 2013

Thesis Advisor:
Second Reader:

Tom Mackin
Lauren Fernandez

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**FORMULATING A STRATEGIC RESPONSE PLAN FOR A HIGH-RISK
SEISMIC EVENT IN NEW YORK CITY**

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Submitted in partial fulfillment of the
requirements for the degree of

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**NAVAL POSTGRADUATE SCHOOL
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ABSTRACT

One of the lessons the Fire Department of New York (FDNY) has learned from the attacks of September 11, 2001, is to be prepared for the inevitable. As one of the world's most renowned emergency response agencies, the FDNY can and should be the model of preparedness for any disaster that may affect New York City (NYC). Historical and scientific data confirms the very real threat of a low frequency, high risk earthquake affecting the NYC region. Potential for devastation is compounded due to the complexity of NYC's infrastructure and the vast population unfamiliar with this type of natural disaster. The formulation of an FDNY pre-plan for a high-risk earthquake scenario based on extensive information-gathering and the assembly of a dedicated focus group will lessen the impact of a powerful quake while minimizing losses to lives, property and emergency responders themselves. By being prepared for the seemingly inevitable, the FDNY can live up to its role as one of the world's most respected emergency response agencies.

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LIST OF ACRONYMS AND ABBREVIATIONS

AUC	All Unit Circular
BART	Bay Area Rapid Transit
BFU	Brush Fire Unit
CIMS	Citywide Incident Management System
Con Ed	Consolidated Edison
DEP	Department of Environmental Protection
DOB	Department of Buildings
DOHMH	Department of Health and Mental Hygiene
DOITT	Department of Information Technology and Telecommunications
DOT	Department of Transportation
DVI	Disaster Victim Identification
EDP	Emotionally Disturbed Person
FD	Fire Department
FDNY	Fire Department of New York
FDOC	Fire Department Operations Command
IAP	Incident Action Plan
M	Magnitude
NISA	Nuclear and Industrial Safety Agency
NPO	Non-Profit Organization
NRC	Nuclear Regulatory Commission
NY	New York

NYC	New York City
NYCEM	New York City Area Consortium for Earthquake Loss Mitigation
NYCTA	New York City Transit Authority
NYPD	New York Police Department
OEM	Office of Emergency Management
PA	Port Authority
PD	Police Department
PNSN	Pacific Northwest Seismic Network
PG	Pre-incident Guideline
R & D	Research & Development
RRV	Rapid Response Vehicle
SOC	Special Operations Command
SOP	Standard Operating Procedures
TEPCO	Tohoku Electric Power Company
UN	United Nations
USAR	Urban Search and Rescue
USCG	United States Coast Guard
USGS	United States Geological Survey

EXECUTIVE SUMMARY

The attacks of September 11, 2001, were an unexpected and tragic event; a “black swan.” If these attacks have taught us anything, it is to be prepared for the unimaginable. One seemingly unimaginable disaster is an earthquake affecting America’s largest city, the city of New York. History and scientific data has shown that New York City (NYC) is susceptible to a seismic event between magnitudes of 4.7 and 7.0. Due to the low frequency of quakes in the NYC region, the complexity of its infrastructure, the lack of specific earthquake driven building codes and the unfamiliarity of its citizens and emergency responders with this type of event, the potential for extensive loss of life and livelihood can be considered much greater compared to other, more prepared cities located in known seismic zones.

As one of the world’s most renowned emergency response agencies, the FDNY can and should be the model of preparedness for an earthquake in NYC. Whether the epicenter of the quake is within the city itself or hundreds of miles away, the potential for devastation is great. That potential is compounded by factors such as NYC’s vast population, variety of structures, complex infrastructure, aged utility network and dependence on a multitude of bridge and tunnel connections. In order to prepare the FDNY for such an event, threats related to earthquakes are made known, vulnerabilities specific to NYC analyzed, FDNY response considerations reviewed and case studies of recent earthquakes in urban areas similar to NYC are performed in this thesis.

Ultimately, activities such as committing resources, pushing for public information campaigns, securing funding and overhauling existing FDNY Manuals to account for an earthquake scenario is not the answer. The low frequency of earthquakes in the northeast and expected political and media opposition will not allow these overbearing solutions. More reasonable, however, is the formulation of an FDNY pre-plan for a high-risk earthquake scenario. By putting together a focus group, gathering information from field units and engaging in regular meetings and table-top exercises with Department heads, the FDNY can live up to its role as one of the world’s most

respected emergency response agencies and continue its commitment to the protection of life and property of New Yorkers, becoming truly prepared for the unthinkable.

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I. INTRODUCTION

On August 23, 2011, the residents of New York City (NYC) experienced the tremors of an earthquake. According to Fox News, “no damage was reported, but 911 calls flooded [the police call lines] and jammed the wireless phone networks.”¹ Although no one was hurt as a result of the earthquake, there was a spike in calls to both New York’s 911 and 311 lines in the hours following the event.² The source of the tremors was a 5.8-magnitude earthquake with an epicenter in central Virginia, about 38 miles northwest of Richmond.³ This occurrence raised serious questions as to the vulnerability of New York to a major seismic event. First, are East Coast cities generally susceptible to earthquakes or was this event an anomaly? Second, how was the Virginia quake felt by people as far away as New York? Third, is the NYC area directly prone to quakes, aside from tremors that travel hundreds of miles, and, finally, are NYC’s residents and infrastructure vulnerable to seismic loads? More important questions involve the capabilities of first responders should another seismic event occur. What would be the short-term and long-term implications for service disruptions throughout the NYC’s five boroughs? What dangers can be avoided or pre-planned for considering the vast network of underground gas mains and electric conduits? How can the Fire Department of New York (FDNY) manage water supply to fight fires following the likely destruction of water mains throughout the city? And finally, how can crucial resources, including personnel, be distributed to areas of need in a city largely connected by bridges and tunnels?

A. PROBLEM STATEMENT

Earthquakes can and do occur in and around the NYC area. Such seismic activity, although infrequent, should not be overlooked. It is inevitable that one day the citizens of

¹ Myfoxny.com. “Earthquake Felt in New York City,” (2011).
<http://www.myfoxny.com/dpp/news/earthquake-felt-in-new-york-city-20110823>.

² Ibid.

³ Ibid.

America's largest city will experience a moderate to severe earthquake and it is imperative that first responders of NYC and surrounding jurisdictions have a plan of action for this black swan. The August 23, 2011, magnitude (M) 5.8 earthquake frightened many New Yorkers.⁴ A Columbia University study conducted by Lynn Sykes and other members of the Lamont-Doherty Observatory analyzed recent earthquake activity around NYC and found that many small faults previously believed to be inactive could contribute to a major, disastrous earthquake.⁵⁶ The study also found that a line of seismic activity comes within two miles of the Indian Point Nuclear Power Plant, located about 25 miles north of NYC.⁷ Another fault line near the plant was already known, suggesting the Indian Point facility to be at an intersection of faults.⁸ According to Dr. Lerner-Lam, head of the Lamont-Doherty Division of Seismology at Columbia University, “we do expect earthquakes to occur here, not as frequently as in California, but [the August 23 quake] is not a surprise.”⁹

Fault lines within the New York area are not the only problem. Concerning the geology of the East Coast, W. Craig Fugate, Administrator of FEMA, stated that “the hard rock transmits the energy of the earthquake longer distances.”¹⁰ As proved by the tremors felt on August 23, 2011, an earthquake with an epicenter in a rural area hundreds of miles away could have far-reaching effects on a major city such as NYC. To compound the problem in this scenario, due to the geology of the East Coast and the

⁴ USGS.gov. “Magnitude 5.8 – VIRGINIA,” (August 23, 2011).
<http://earthquake.usgs.gov/earthquakes/recenteqsw/Quakes/se082311a.php>.

⁵ Lynn R. Sykes. “*Earthquakes May Endanger New York More Than Thought, Says Study*,” Lamont-Doherty earth Observatory. (August 5, 2008). <http://www.ledo.columbia.edu/news-events/earthquakes-may-endanger-new-york-more-than-thought-says-study>.

⁶ “Study Finds New Earthquake Dangers for NYC.” NBCNEWS.com. (August 23, 2008).
http://www.msnbc.msn.com/id/26361143/ns/us_news-life/t/study-finds-new-earthquake-dangers-nyc/Msnbc.com.

⁷ Ibid.

⁸ Ibid.

⁹ Katherine Q. Seelye. “Above All Else Eastern Quake Rattles Nerves,” The New York Times.
http://www.nytimes.com/2011/08/24/us/24quake.html?_r=1&pagewanted=allNytimes.com.

¹⁰ Ibid.

resultant spread of seismic waves, aid cannot be relied on from adjoining jurisdictions as these cities and towns may also be overwhelmed from the effects of the quake.

As the attacks of September 11, 2001 demonstrated, failure to expect the unexpected can have disastrous consequences. Earthquakes can and do affect the NYC area, however sparingly they occur. In fact, the lack of familiarization with earthquakes along the eastern seaboard can prove to be especially problematic as the population, unlike their west-coast counterparts, will be unprepared for seismic tremors. It is for this reason that a plan of action for an earthquake response is warranted and as one of the most dependable and experienced emergency response agencies in the world, the FDNY should become the model for this level of preparedness.

It would be unjustifiable for the FDNY to use much of its limited financial resources and training activities to prepare for an event that may or may not occur in its current members' lifetimes. However, this does not mean that its members should be caught off-guard. By formulating a plan of action among the FDNY's most senior leaders, the Department will be able to respond quickly and effectively in the event of a moderate to severe earthquake in or around NYC. Additionally, on-duty training of field units can be facilitated utilizing the Fire Department's "Diamondplate" training website while mid-level supervisors develop creative solutions to local problems during scheduled building inspection and drill periods. One of the most important ways to begin preparing for this event is by exposing the city's vulnerabilities, while forming a plan of action based on previous earthquake responses in other major urban areas. By emulating the successes and identifying the failures of other emergency response departments, as well as exposing NYC's vulnerabilities, the highest ranking members of the FDNY can draw probable conclusions regarding what they are likely to face in the event of a similar devastating earthquake and truly be prepared for the next black swan.

B. LITERATURE REVIEW

To expose NYC's vulnerabilities, the causes, consequences and characteristics of earthquakes must be identified. Well known by many science professionals as a leading

authority on earthquakes, the United States Geological Survey (USGS) is a science organization that strives to provide impartial information on the health of the ecosystem and environment, natural hazards, natural resources and climate and land-use change.¹¹ A fact-finding research organization with no regulatory responsibility, the USGS employs approximately 8,670 scientists, researchers and experts and is headquartered in Reston, Virginia.¹² This organization informs authorities, emergency responders, the media and the domestic and worldwide public about significant earthquakes. It also maintains archives of earthquake data for scientific and engineering research, while supporting studies on long-term seismic hazards.¹³

According to historical records provided by the USGS, a number of earthquakes have had negative effects for residents of the New York area. Though the historical evidence of earthquakes throughout the northeastern portion of the U.S. is undeniable, past events do not predict, with certainty, the future. Given the statistical nature of seismic events, geologists generally have an aversion to unduly alarming the populace.¹⁴ In a New York Times interview with Dr. Arthur Frankel, a seismologist with the USGS in Colorado, in response to the question of whether NYC is susceptible to an earthquake, Dr. Frankel stated that “the quake hazard in this [NYC] region is significant... it isn’t as high as it is in California, but because of the high population and the built-up infrastructure, the risk is significant.”¹⁵ The facts illustrate that New York’s largest city has experienced earthquakes in the past and, since the forces that generate quakes have not disappeared, it can be assumed that NYC will experience such tremors in the future. Ruth Ludwin, a research scientist with the Pacific Northwest Seismic Network (PNSN) tends to agree with members of the USGS. PNSN is an organization dedicated to reducing impacts of earthquakes and volcanic eruptions in the states of Washington and

¹¹ USGS.gov. <http://www.usgs.gov/aboutusgs>.

¹² USGS.gov. “USGS Visual Identity System.” http://www.usgs.gov/visual-id/outside_use.html.

¹³ USGS.gov. http://www.usgs.gov/start_with_science.

¹⁴ NYTimes.com.
http://www.nytimes.com/2007/11/13/nyregion/13quake.html?_r=1&ref=nyregion&oref=slogin.

¹⁵ Ibid.

Oregon. According to their website, the mission of the PNSN is to monitor ground motions within the region to better understand earthquakes, provide the most accurate information as rapidly as possible to public officials and the public, and advocate comprehensive and cost-effective measures for reducing the harmful effects of earthquakes and volcanoes.¹⁶ According to the PNSN, although a great deal is known about where earthquakes are likely, there is currently no reliable way to predict the days or months when an event will occur in any specific location.¹⁷ And so, although a quake is likely to affect NYC in the future, there is no reliable way of knowing exactly when this will occur.

Many sources can be utilized to prepare NYC first responders for an impending earthquake. The first is the official manuals of the FDNY. These books contain no specific standard operating procedures (SOP) for earthquake response; however, they do provide instruction for individual situations involving building collapse, gas leak mitigation, fire control and basic water flooded conditions. Although these manuals provide effective SOP's at the tactical level, more needs to be accomplished strategically. A focus group and information-gathering headed by the most senior levels of the Department are recommended to prepare for such an event. Case studies, including failures and successes in earthquake response across the globe, are analyzed and earthquake-specific topics such as tsunamis, aftershocks and the need for specialized rescue procedures assessed.

NYC's Office of Emergency Management (OEM) website contains a section dedicated to earthquakes, stating that, "although earthquakes are uncommon in New York City, tremors occasionally occur, and residents should be prepared."¹⁸ OEM provides a very basic overview for the public should an earthquake occur, including ways to identify safe places in the home, keeping clear of windows and preparing the home by securing

¹⁶ PNSN. http://www.ess.washington.edu/SEIS/PNSN/INFO_GENERAL/eq_prediction.html.

¹⁷ Ibid.

¹⁸ NYC OEM. <http://www.nyc.gov/html/oem/html/hazards/earthquakes.shtml>.

heavy objects. OEM states that after an earthquake “your utilities may be disrupted.”¹⁹ NYC’s true vulnerability due to its aged infrastructure and utility network must be given consideration. NYC’s vast network of water pipes, steam pipes, gas lines and underground and overhead electric lines combined with tunnels, bridges and buildings, some over a century old, will be a major problem during a moderate or severe quake. Ownership of these utilities has changed often throughout NYC’s history, and maps, if made available to emergency managers during an operation, may not always be reliable and in many cases, may even be inaccurate.

In order to ensure FDNY response procedures are effectively analyzed, a number of different sources, from online content to earthquake-specific literature, are utilized and over one-hundred sources cited. Literature authored by Kate Ascher, an expert in studies of government, corporate finance and economic development, is extensively cited, as she provides detailed descriptions of the various portions of NYC’s infrastructure. The USGS is used for a vast amount of earthquake-related data as official engineering, utility and government online content assist in the analysis of New York’s building design, essential services, population and special projects. Additionally, magazine articles, periodicals and news reports are utilized to provide in-depth details surrounding circumstances of various earthquakes across the globe. Finally, sources citing post-quake actions taken by international response teams and government agencies are reviewed and compared to the FDNY’s current SOP’s.

According to a Fox news report regarding the latest tremors felt by NYC residents during the Virginia quake in August, 2011, “though we hardly felt any movement here in the city of New York as a result of the earthquake, panic seemed to overtake a lot of people, as indicated by various news programs and social networking sites. A single tremor was enough to cause mass confusion, building evacuations and cell phone service outages across the city.”²⁰ This is an example of the level of unpreparedness NYC faces.

¹⁹ NYC OEM. <http://www.nyc.gov/html/oem/html/hazards/earthquakes.shtml>.

²⁰ Manny Alvarez. “Earthquake Proves NYC Is Not Prepared for Natural Disasters.” Foxnew.com. (August 24, 2011). <http://www.foxnews.com/health/2011/08/24/earthquake-proves-nyc-is-not-prepared-for-natural-disasters/>.

The FDNY needs to adopt a new level of pre-planning and resource allocation in the event of this black swan event. The attacks of September 11, 2001 proved that a vast metropolitan area like NYC should be prepared for the inevitable, and as the leading NYC emergency response agency, the FDNY should be the model of this level of preparedness.

C. RESEARCH QUESTION

How can the FDNY Prepare for a High Risk, Low Frequency Seismic Event in New York City?

D. METHOD

The occurrence of an earthquake with an epicenter in or around the city of New York is a very real possibility. However, due to the low frequency of past quakes in the NYC area, extensive data for the true seismic hazard is lacking. Additionally, historical records portray earthquake effects during a time when the population, buildings and infrastructure of NYC differ than what exists today. An analysis of the major threats facing NYC is conducted through research of earthquake-related events such as tsunamis and aftershocks. The anatomy of NYC is explored utilizing numerous published books and web resources. Coupled with FDNY established standard operating procedures, weaknesses in NYC's infrastructure can be identified and plans formulated for dealing with these problems. Finally, the Indian Point Nuclear Power Plant is assessed and potential dangers analyzed using various articles, studies and expert opinions.

In order to formulate an effective strategy for dealing with this potential black swan, case studies of recent earthquakes in various cities, similar in size and scope to NYC, are performed. Though it is generally accepted that the United States' ability to respond exceeds most other countries due to its technological and financial standing, and superior building codes, in relation to other members of the international community, these case studies still provide useful benchmarks for evaluating particularly devastating quakes. An analysis of the challenges posed to responders of modern urban centers in the aftermath of an earthquake, as well as a critique of urban emergency response systems,

provides valuable information, allowing emulation of successes and avoidance of failures. The specific case studies are analyzed as follows as each incident involved a “modern-day” emergency response within a major city comparable to NYC:²¹

- Port-Au-Prince, Haiti Earthquake; January 12, 2010: A city devastated by a recent earthquake that relied heavily on highly trained United States (U.S.) personnel for rescue and recovery is examined. The Port-Au Prince quake shows the devastation that can result from unprepared communities located in low-income areas. NYC itself has many such communities throughout its various boroughs and though building codes are more stringent, public and communal reaction to this quake deserves consideration. This event is analyzed to show the mass devastation that may occur in the immediate aftermath of a very powerful quake. Positive aspects of this specific case study revolve around the success of trained American response teams. The effort and speed involved in importing valuable human resources from America to a devastated area is evaluated and compared to what can be expected in NYC.
- Chile Earthquake; February 27, 2010: An extremely large earthquake affecting a large number of cities along the Chilean coast, with most damage centered in Santiago, a large sprawling urban center, is examined. This earthquake affected a number of communities located along the Chilean coast, not unlike major cities surrounding NYC, along the U.S. East Coast. An after-action-review of the response proves helpful in formulating a strategy for dealing with a quake affecting the numerous populated cities along America’s East Coast.
- Japan Earthquake; March 10, 2011: With Tokyo being a large, populated city, similar in scope to NYC including a vast underground subway system, and located in an earthquake-prone zone, there is much to be learned regarding Japan’s level of earthquake preparedness. Additionally, Urban Search and Rescue (USAR) team response to this specific event as well as the implications of the Fukushima Nuclear Power Plant melt-down are extensively analyzed.
- Christchurch, New Zealand Earthquake; February 22, 2011: Occurring in a large, modern urban area similar to many parts of NYC, the response to the Christchurch quake was exemplary and a model for all emergency managers. This coastal, populated city that experienced a strong earthquake labeled as the second worst disaster in New Zealand’s history proves invaluable in analyzing the positive and negative aspects of

²¹ The building codes in some of the aforementioned case studies are significantly inferior as compared with NYC. As damage is caused by a complex interaction between ground motion and structural composition based on building codes, it can be expected NYC will fare considerably better than some of the cities studied (i.e., Haiti).

modern-day response capabilities following the aftermath of a seismic event.

- Loma Prieta, California Earthquake; October 17, 1989: A widely publicized earthquake affecting populated coastal cities and towns most similar to NYC in American values and societal norms, as well as emergency response capabilities, is compared to the other case studies. Occurring in 1989, it is important to review lessons learned as well as technological developments since that time. This is the oldest case study reviewed but the one in which the most information is available and applicable. Additionally, civilian reaction, emergency response and media coverage of this event is comparable to what can be expected in NYC due to cultural similarities.

An analysis of vulnerabilities is conducted, identifying specific problems first responders are likely to face including utility emergencies, bridge, tunnel and subway system collapse, hi-rise structure challenges, water supply disruption, and difficulty transporting necessary resources as well as acquiring recalled personnel and help from adjoining cities and jurisdictions. As NYC is a city of islands, easily cut off from one another should a quake destroy bridges and tunnels, each borough is given a potential hazard score based on its extent of vulnerability in areas ranging from population to number of unreinforced masonry structures. These scores are totaled, allowing FDNY management to prioritize resource allocation by borough in the event of a large, unexpected earthquake.

A review of the case studies, along with an analysis of NYC's vulnerabilities and specific FDNY pre-plan considerations result in a number of recommendations and implementations FDNY officials can utilize to enhance the Department's capabilities. From local fire departments dealing with the aftermath of the Loma Prieta quake of 1989 to emergency responders attempting to mitigate the nuclear meltdown caused by a tsunami off of the coast of Japan, much is gained by studying the successes and failures of various agencies located in seismic "hot-zones" and applying lessons learned to NYC's own specific challenges.

No city is an exact replica of NYC, but many of the cities that are analyzed in these case studies have similar features, including, but not limited to, skyscrapers, aged

infrastructure and underground subway systems. Through the use of articles, media reports, online journals and after-action-reviews, data is collected and critiqued. Emulating successful responses in these cases studies, while learning from mistakes, allows a competent strategic operating plan to be formulated. Additionally, data retrieved from online sources and acknowledged written material regarding population, infrastructure and response capabilities specific to NYC is used to formulate this strategy. Specific response considerations applicable to the FDNY are analyzed taking into account NYC's geographic location, infrastructure, resources and past FDNY challenges. A thorough analysis of the aforementioned case studies coupled with data pertaining to the modern-day structure and infrastructure of NYC permits a dependable, effective plan to be formulated for this black swan event.

II. ANALYSIS OF MAJOR THREATS

A. EARTHQUAKE HAZARD IN NY

Earthquakes are common natural events that occur every day, all over the world. They result from the motion of tectonic plates moving slowly over the mantle that slide past each other, push into each other, move away from each other, or slip under one another.²² It is on these active plate boundaries that about 95% of all the world's earthquakes occur, with poorly understood mid-plate quakes (such as the New Madrid) making up the remaining 5%. Some of the most earthquake-prone areas of the world, including California, Alaska, Japan, South America and the Philippines are all on plate boundaries.²³ The closest plate boundary to NYC is thousands of miles away in the middle of the Atlantic Ocean. Yet, despite its intra-plate location, the city has an unusually high number of earthquakes. With over one million quakes annually across the earth's surface, most are too small to be felt.²⁴ Table 1 shows the average frequency of different magnitude earthquakes.

22 Center for Earthquake Research and Information.
<http://www.ceri.memphis.edu/awareness/follies.html>.

23 Ibid.

24 "New York City Geology." Earth and Planetary Sciences. <http://research.amnh.org/eps/nycgeology>.

Table 1. Frequency of Differing Earthquake Magnitudes (From: Earthquakes and the Urban Environment, Vol. 1, G. Lennis Berlin, 1980).

Description	Magnitude	Frequency per year
Great	8.0+	1
Major	7.0–7.9	18
Large (destructive)	6.0–6.9	120
Moderate (damaging)	5.0–5.9	1,000
Minor (damage slight)	4.0–4.0	6,000
Generally felt	3.0–3.9	49,000
Potentially perceptible	2.0–2.9	300,000
Imperceptible	less than 2.0	600,000+

Using the previous table, one can discern a rate of approximately 80,000 quakes per month, 2,600 per day and 2 per minute.²⁵ These data can also be organized into exceedance probability plots. Exceedence probability is the likelihood that an event of specified magnitude will be equaled or exceeded in a defined period of time; in this case, per year. Figure 1 plots the exceedance probability against the quake size. Such plots allow one to estimate the annual likelihood of a particular earthquake magnitude anywhere in the world and as portrayed in Figure 1, though earthquakes are quite common, damaging quakes are rather rare.

²⁵ Center for Earthquake Research and Information.
<http://www.ceri.memphis.edu/awareness/follies.html>.

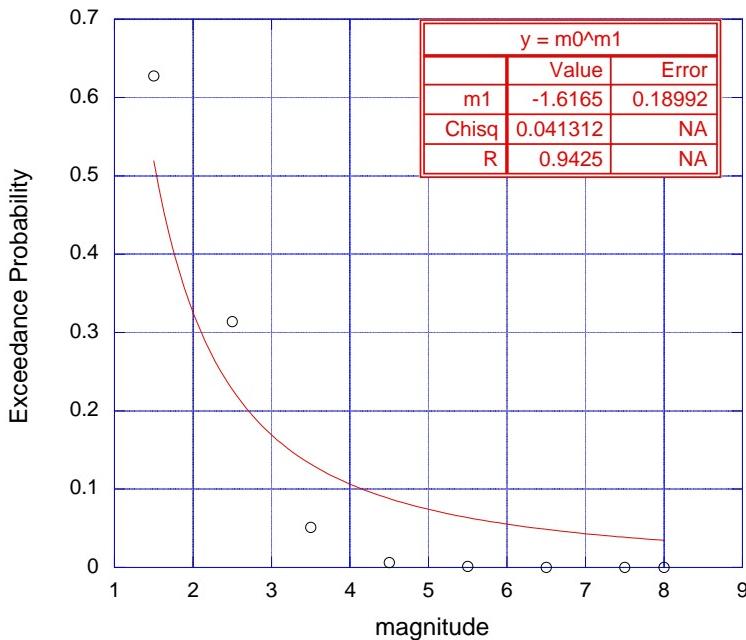


Figure 1. Exceedance Probability Plot for Annual Earthquake Occurrence Worldwide.

With approximately one earthquake occurring every 30 seconds, only a relative few are capable of causing damage. Though a number of factors affect the lethality of an earthquake and the amount of damage it can inflict, it is the confluence of multiple factors that create major consequences. Large quakes in populated regions with poor construction standards can have devastating consequences. The largest known earthquake measured an M 9.5 and occurred in Chile in 1960, resulting in over 6,000 deaths. Compare that to the great Alaska earthquake of March 27, 1964, the largest known earthquake to have occurred in the United States at M 9.2, which resulted in only 115 deaths, most due to the tsunami it generated.²⁶ The amount of energy generated during the 1964 Alaska quake, which generated ground surface movements between 2 and 17 meters, was equivalent to 12,000 Hiroshima-type blasts, or 240 million tons of TNT.²⁷

²⁶ Center for Earthquake Research and Information.
<http://www.ceri.memphis.edu/awareness/follies.html>.

²⁷ Center for Earthquake Research and Information.
<http://www.ceri.memphis.edu/awareness/follies.html>.

Earthquakes release a tremendous amount of energy which is why they can be so destructive. Table 2 displays earthquake magnitudes with the approximate amount of TNT needed to release the same amount of energy.

Table 2. Approximate TNT Energy for Differing Earthquake Magnitudes (From: Earthquakes and the Urban Environment, Vol. 1, G. Lennis Berlin, 1980).

Magnitude	Approximate TNT Energy
4.0	6 tons
5.0	199 tons
6.0	6,270 tons
7.0	199,000 tons
8.0	6,270,000 tons
9.0	99,000,000 tons

In some areas of the world, smaller earthquakes are responsible for the deaths of many thousands of people, primarily because of poorly designed buildings, unprotected infrastructure, large population density, and in many cases, lack of planning. Table 3 demonstrates some of the major earthquakes that have occurred around the world in the last twenty years, and the number of deaths associated with them.

Table 3. Death Tolls of Major Earthquakes (From: Earthquakes and the Urban Environment, Vol. 1, G. Lennis Berlin, 1980).

Year	Date	Region	Deaths	Magnitude
1971	02-09	Southern California	65	6.5
1972	12-23	Managua, Nicaragua	5,000	6.2
1976	02- 04	Guatemala	22,000	7.9
1977	07-27	Tangshan, China	250,000+	7.6
1980	03- 04	Romania	2,000	7.2
1980	10- 10	Algeria	35,000	7.7
1981	11-23	Southern Italy	3,000	7.2
1982	06-11	Southern Iran	3,000	6.9
1983	12- 13	Yemen	28,000	6.0
1985	10- 30	Turkey	1,342	6.0
1985	12- 07	Armenia	25,000	6.9
1989	09- 19	Mexico	10,000	7.0
1990	06-20	Iran	40,000	7.7

Many individuals mistakenly believe that earthquakes only occur in other parts of the world and that their hometown is not susceptible. Some uninformed inhabitants of America's East Coast may perceive seismic events as a "West Coast" problem. Nothing could be farther from the truth. All areas of the world are prone to seismic activity, though some more frequent, and disastrous, than others. A major problem results when this natural event occurs in or around a complex city with high population density, aged infrastructure and unprepared emergency response agencies. Unfortunately NYC may be especially susceptible to the disastrous consequences of an earthquake due to the low frequency, and resulting lack of familiarity, with these events. In order to properly assess the threat, it is important to analyze how likely it is for an earthquake to occur in or around NYC. To start, one must look back into NYC's history.

Novelist George Santayana has been quoted as saying "those who cannot remember the past are condemned to repeat it."²⁸ The NY area has had a significant number of earthquakes since modern record-keeping began. Below is a short list put forward by the USGS detailing the history of earthquakes that have affected NYC.²⁹

- December 18, 1737: An earthquake near NYC threw down a number of chimneys. The shock was reportedly felt in Boston, Philadelphia and New Castle, Delaware.
- November 4, 1877: A rather severe earthquake centered in northeastern New York caused moderate damage along the St. Lawrence River and in the Lake Champlain. Crockery was overturned, ceilings cracked and chimneys were thrown down. The earthquake was felt throughout a large part of New York, New England and Eastern Canada.
- May 27, 1897: A shock reported as severe, but with no damage noted, occurred in northeastern New York. It was felt over the greater portion of New York and parts of adjacent New England States as well as Quebec, Canada.
- February 28, 1925: An M 7 earthquake shook a very large area of the northeastern United States and eastern Canada. A large portion of New York State experienced intense effects.

28 George Santayana. "Life of Reason, Reason in Common Sense," Scribner's, 1905, 284.

29 "New York: Earthquake History."
http://earthquake.usgs.gov/earthquakes/states/new_york/history.php.

- August 12, 1929: Extensive damage occurred in the Attica area from a strong shock. Chimneys were thrown down, plaster was cracked or thrown down, and other building walls were noticeably damaged. The earthquake was felt throughout most of New York and the New England states, northeastern Ohio, northern Pennsylvania and southern Ontario, Canada. Additionally, an increased flow at the Attica reservoir was noted for several days after the earthquake and a number of wells near the reservoir went dry. It should be noted here that an earthquake hundreds of miles from NYC can cause a number of problems involving the city's infrastructure including water supply and the power grid.
- November 1, 1935: A strong earthquake centered near Quebec, Canada caused slight damage at many points in New York. The damage was limited, in general, to plaster cracks, broken windows and cracked chimneys. The shock was felt throughout New York, as far south as Washington, D.C., and as far west as Wisconsin.
- December 24, 1940: An earthquake centered near Lake Ossipee, New Hampshire caused widespread, though slight, damage in the epicenter-region. The damage extended into Maine, Massachusetts, Rhode Island and Vermont. The shock was felt over all of New York State.
- September 4, 1944: An earthquake centered about midway between Massena, New York and Cornwall, Ontario was felt over all of the New England States, Delaware, Maryland, New Jersey, Pennsylvania, and portions of Michigan and Ohio. A few points in Illinois, Indiana, Virginia, West Virginia and Wisconsin also reported feeling the tremor.
- January 1, 1966: An M 4.7 disturbance caused slight damage to chimneys and walls at Attica and Varysburg, NY. Plaster fell at the Attica State Prison and the main smokestack was damaged.

The historical records confirm that earthquakes in other areas of NY, and even the continental U.S., can have far-reaching effects for the residents of NYC. Some scientists believe that the greatest earthquake risk east of the Rocky Mountains is along the New Madrid fault system, a fairly active zone located in the Midwestern portion of the United States.³⁰ Figure 2 illustrates the risk of damage from earthquakes in the United States. Although NYC is in a low risk zone for the origination of quakes, it borders other high risk zones that may well transmit significant seismic loads to the NYC area. Additionally, even though damaging earthquakes are much less frequent along the East Coast than in

³⁰ Center for Earthquake Research and Information.
<http://www.ceri.memphis.edu/awareness/follies.html>.

California, when they do occur the damage can be far greater due to the underlying geology.³¹ A series of four great earthquakes occurred in the Central United States between December 16, 1811 and February 7, 1812. All had estimated magnitudes greater than M 7.5.³² Collectively known as the New Madrid Earthquakes, effects were felt over an estimated 2 million square miles, far greater than any other recorded quake in the United States.³³ Because of the small number of people living in the area at the time, however, fewer than 100 deaths were recorded.³⁴ The quake caused extensive damage to structures and extraordinary changes to land surfaces throughout the region, as well as sending shockwaves as far away as Boston, Massachusetts.

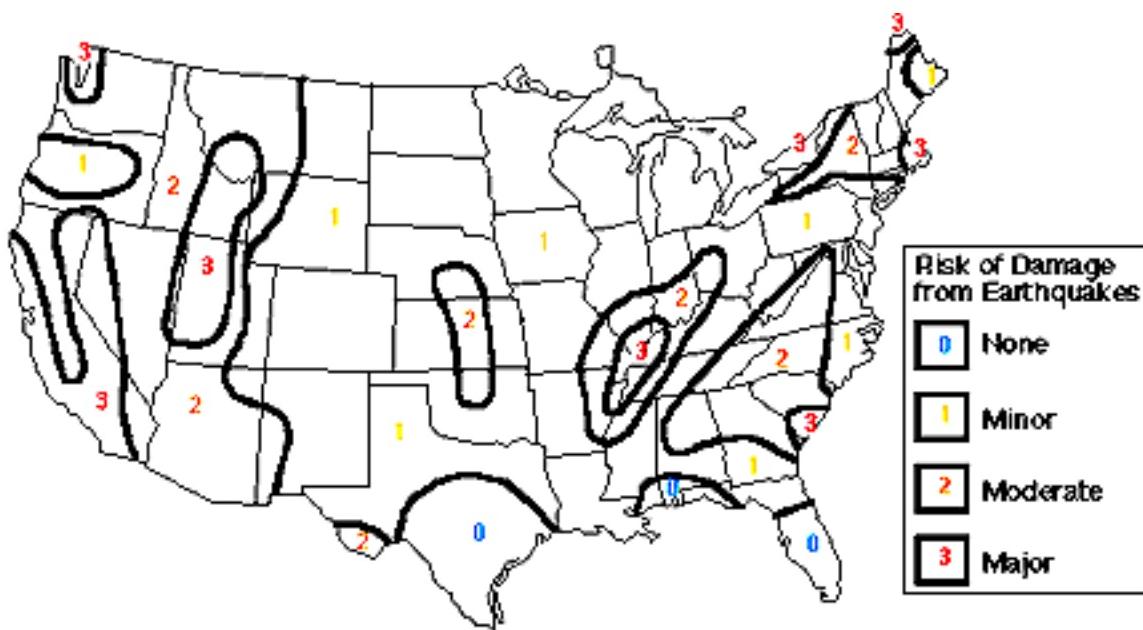


Figure 2. Risk of Damage from Earthquakes in the U.S. (From: Stearns and Miller, 1977).

³¹ Center for Earthquake Research and Information. <http://www.ceri.memphis.edu/awareness/follies.html>.

³² Ibid.

³³ Ibid.

³⁴ Ibid.

The records clearly show that seismic activity hundreds of miles from the New York area has affected NYC residents as well as neighboring jurisdictions. The earthquake threat, however, also exists within the vast metropolitan area itself. The last major quake within NYC occurred more than a century ago on August 10, 1884, at 7:07 p.m.³⁵ An earthquake measuring M 5.2 on the Richter Scale had its epicenter in New York Harbor south of Rockaway Beach, toppling chimneys, ringing church bells and breaking crockery from Connecticut to Pennsylvania.³⁶ Its effects were noted from Virginia to Maine. According to Dr. Arthur Frankel, a seismologist with the USGS in Colorado, “That size event would cause much more damage now due to the greater population, proliferation of buildings and infrastructure.”³⁷ According to Dr. Frankel, some geologists believe the quake like the one that occurred in NYC in 1884 may occur once every 50 to 100 years, with a stronger M 6 quake potentially striking every 400 to 500 years.³⁸ The last quake of that size occurred at Cape Ann off the coast of Massachusetts in 1755.³⁹ According to Dr. Frankel, the effect of a major quake in the NYC area “is something we need to worry about and prepare for.”⁴⁰ The latest data shows that New York, New Jersey and Connecticut are riddled with ancient geological faults and one of the most visible faults crosses the island of Manhattan at 125th Street, creating a distinct valley near the Hudson River. As clearly illustrated in Figure 3, the

³⁵ Glenn Collins. “Picking Up City’s Vibes to Predict Quake Effects,” NYTimes.com. (November 13, 2007), <http://www.nytimes.com/2007/11/13/nyregion/13quake.html?pagewanted=print>.

³⁶ Ibid.

³⁷ Ibid.

³⁸ Ibid.

³⁹ Ibid.

⁴⁰ Ibid.

NYC area is at the middle of the scale of lowest to highest hazard in analyzing the potential for earthquakes.⁴¹ Figure 4 further portrays the earthquake hazard along the East Coast.⁴²

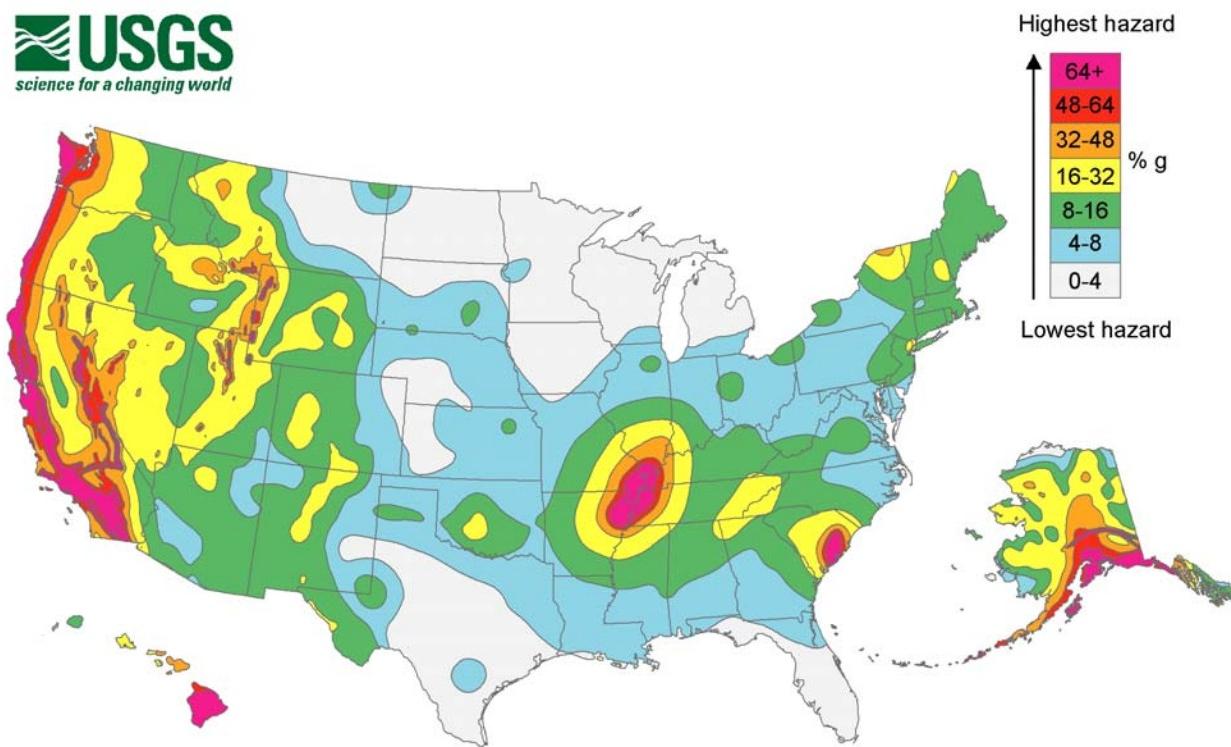


Figure 3. USGS National Seismic Hazard Map 2008. (From: The USGS. <http://earthquake.usgs.gov/hazards/product>).

⁴¹ These maps are the basis for seismic design provisions of building codes, insurance rate structures, earthquake loss studies, retrofit priorities and land-use planning. Their use in design of buildings, bridges, highways and critical infrastructure allows structures to better withstand earthquake shaking, saving lives and reducing disruption to critical activities following a damaging event. “Hazard Mapping Images and Data,” USGS. <http://earthquake.usgs.gov/hazards/products>.

⁴² “Understanding Hazards in the Central and Eastern U.S.,” USGS. <http://earthquake.usgs.gov/regional/ceus/>.

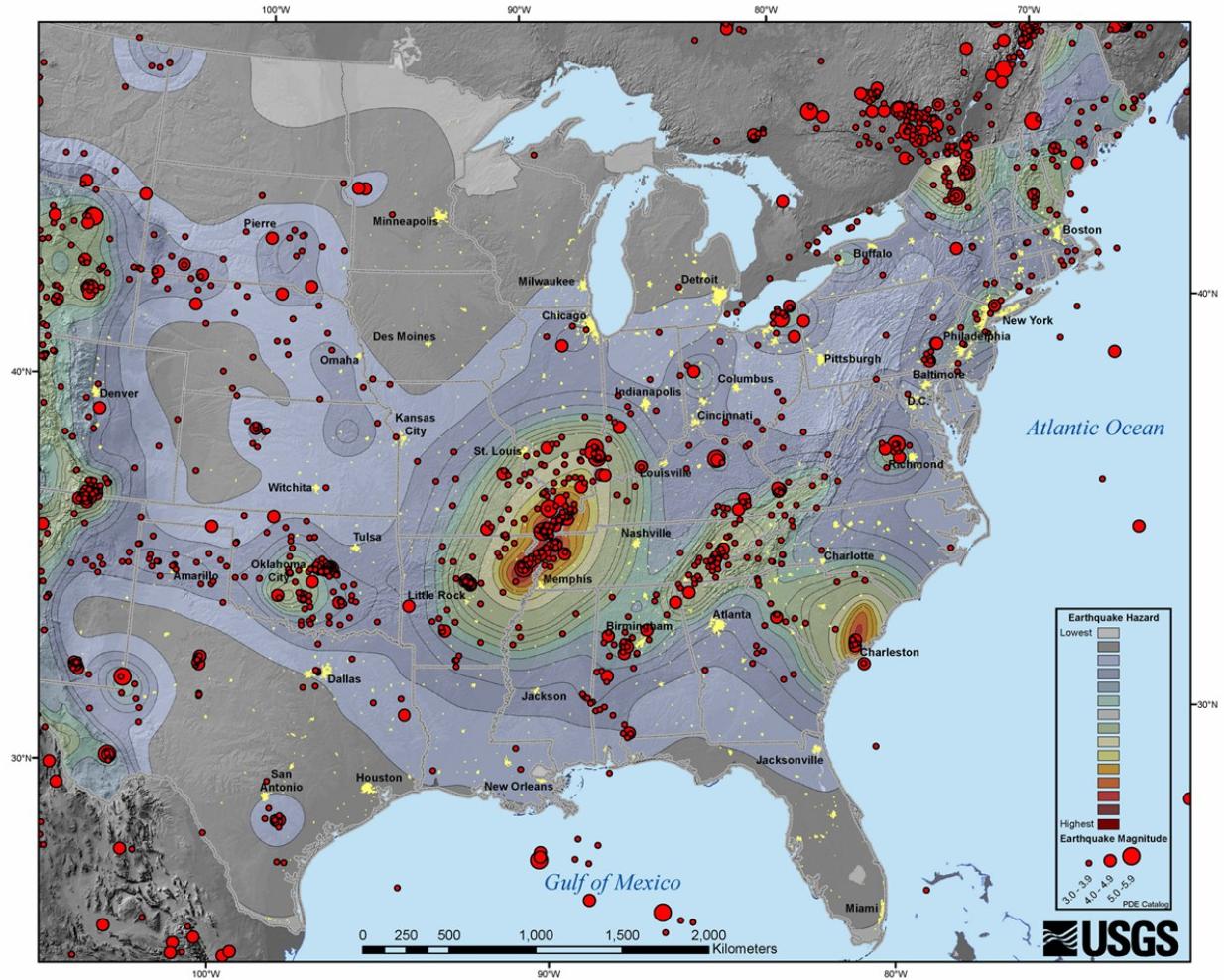


Figure 4. Earthquake Hazard Areas across the East Coast. (From: The USGS.
<http://earthquake.usgs.gov/regional/ceus/>).

In Dr. Frankel's opinion, the effects of a severe earthquake in Manhattan could be more profound than those in the West because on the East Coast, the earth's rocky crust is older, cooler, more rigid and capable of transmitting more powerful shock waves in comparison to the younger Western bedrock.⁴³ The lack of anticipation or knowledge regarding earthquakes in the NY region is also a problem. Many individuals hastily call 911 when something is amiss but are ill prepared to be self-sufficient following a large-

⁴³ "Understanding Hazards in the Central and Eastern U.S.," USGS.
<http://earthquake.usgs.gov/regional/ceus/>.

scale disaster. Dr. Won-Young Kim, a senior research scientist at Lamont-Doherty Earth Observatory of Columbia University, is the director of a seismic network that monitors earthquakes in the New York region. Dr. Kim employs a network of scientists and volunteers who give anecdotal reports of the shaking effects of earthquakes, such as four small seismic events, less than M 1, which took place from Dec. 12 to 14 in 2004. In a New York Times Interview discussing these tremors, Dr. Kim stated “people certainly felt them; there were 150 calls to police.”⁴⁴

Table 4 illustrates the potential impact of a variety of earthquake scenarios in and around New York City as modeled in the New York City Area Consortium for Earthquake Loss Mitigation (NYCEM) Study published in 2003.⁴⁵ In the case of an M 6 earthquake, which is considered a moderate event, the total devastation for the Tristate Area (NYC, NJ and CT) is quite high, in all a total economic loss of almost \$40 billion.

⁴⁴ “Understanding Hazards in the Central and Eastern U.S.” USGS, <http://earthquake.usgs.gov/regional/ceus/>.

⁴⁵ The New York City Area Consortium for Earthquake Loss Mitigation, http://www.dhses.ny.gov/oem/mitigation/archive/documents/S3.I.vi_Earthquake_Hazard_Profile.pdf.

Table 4. A Summary of the Findings of the NYCEM Report. (From: Division of Homeland Security and Emergency Services.

http://www.dhses.ny.gov/oem/mitigation/archive/documents/S3.I.vi_Earthquake_Hazard_Profile.pdf.

Scenario	Building Damage	Income Losses	Total	Hospitalization	Deaths	Shelter Needs	Fires	Building Complete Damage	Debris
M-5	\$4.4 b	\$0.4 b	\$4.8 b	24	13	2,800	500	45	1.6 m tons
M-6 ⁴⁶	\$28.5 b	\$10.8 b	\$39.3 b	2,296	1,170	197,705	900	2,600	31.9 m tons
M-7	\$139.8 b	\$57.1 b	\$196.8 b	13,171	6,705	766,746	1,200	12,800	132.1 m tons
100-year	\$0.1 b	\$0.1 b	\$0.2 b	0	0	0	0	0	0.2 m tons
500-year	\$6.1 b	\$2.0 b	\$8.1 b	28	14	575	50	100	3.1 m tons
2500-year	\$64.3 b	\$20.4 b	\$84.8 b	1,430	727	84,626	900	2,200	34.0 m tons
9/11/2001 ⁴⁷	\$13.0 b	\$52–64 b	\$98.0 b	6,000	2,753 ⁴⁸	300	10	20	1.6 m tons

Historical evidence and scientific research has demonstrated NYC's susceptibility to a powerful quake, however, initial ground motion is not the only seismic-related danger which may result in devastation. An analysis of additional earthquake-related events such as aftershocks and tsunamis is required, as well as a closer look at the geology located beneath America's largest city, to truly understand the magnitude of the threat.

⁴⁶ *The New York City Area Consortium for Earthquake Loss Mitigation*, http://www.dhses.ny.gov/oem/mitigation/archive/documents/S3.I.vi_Earthquake_Hazard_Profile.pdf.

⁴⁷ NOTE: For this report the events of September 11th 2001 are used as a real life benchmark to be able to make a comparison for the listed earthquake scenarios.

⁴⁸ This is the total number killed in the attacks on the WTC in NYC. This does not take into account deaths outside of the tri-state area that day or deaths related to 9–11 illnesses. “9/11 By the Numbers,” NYMag.com. (September 2012), <http://nymag.com/news/articles/wtc/1year/numbers.htm>.

B. AFTERSHOCKS

Aftershocks are a series of smaller earthquakes occurring after the larger, main earthquake in the same area of the main shock. This type of seismic activity is usually the result of the crust around the displaced fault plane adjusting to the effects of the main earthquake. If the aftershock turns out to be larger than the main shock, then it is redesignated as the main shock, with the original labeled a foreshock. Bigger earthquakes tend to have more frequent and larger aftershocks which in some cases can last for years or even longer. The New Madrid Seismic Zone, cause of the August 23, 2011 quake felt in NYC, still encounters aftershocks resulting from the main shocks of 1811–1812.⁴⁹ The problem with aftershocks is threefold. For one, overall damage is compounded as structures and infrastructure weakened by the main quake become more prone to subsequent destruction, even if the aftershocks are of much smaller magnitude. A building designed to withstand tremors of an M 5 may collapse during an M 3 aftershock if its foundation and/or connections are disturbed during the main earthquake. The second problem with aftershocks is the danger to rescuers. Firefighters performing a void search of a collapsed building, or controlling a fire caused by a ruptured gas main, may be placed at further risk should an aftershock occur during operations. This not only puts rescuers in danger, but it reduces the impact of the overall rescue mission as other first responders spend time and energy saving their own instead of the general population. Finally, aftershocks are likely to cause panic among survivors and a disregard for authority as victims may come to distrust directions from agency leaders (i.e., sleeping in the streets as opposed to Safe Refuge Areas set up by authorities.)

Most scientists agree that an aftershock sequence is deemed to have ended when the rate of seismicity drops back to a background level. In his published work, Fusakichi Omori describes the temporal decay of aftershock rates. In summary, aftershock frequency decreases in relation to the reciprocal of time after the main shock.⁵⁰ Although

49 “Earthquake Definitions,” Rutherford County Tennessee Emergency Management Agency, http://www.rutherfordcountytn.gov/ema/definitions_earthquake.htm.

50 F. Omori (1894), “On the Aftershocks of Earthquakes,” Journal of the College of Science, Imperial University of Tokyo 7: 111–200.

the rates of aftershocks tend to follow patterns, the occurrence, rate and magnitude of these tremors remain quite unpredictable. Some aftershocks may occur hours after the main even while others take years to occur. Overall, according to Omori's equations, the rate of aftershocks decreases quickly with time, and agency leaders should plan with this in mind.

C. LIQUEFACTION

Based on seismic records, a number of geologists accept that there is ongoing tectonic activity in the Northeast U.S. An earthquake here would invariably affect a much wider area and create more damage than what has traditionally been seen on the West Coast because the Earth's crust in the eastern states can transmit seismic energy more efficiently. In fact, for any given earthquake magnitude the resultant ground shaking in the east can reach distances three to six times further, affecting areas 10 to 40 times greater than in the western U.S.⁵¹ The transmission of energy, however, is not the only problem challenging unwary East Coast residents. During the May 25, 1988 M 6 Saguenay earthquake of Quebec, "liquefaction" was observed at a distance of 15 ½ miles from the epicenter, approximately ten times larger than the maximum distance observed in the west during similar magnitude earthquakes.⁵² Liquefaction is a phenomenon whereby a saturated soil loses strength and stiffness due to an applied stress, such as shaking, as a result of an earthquake. This geological process can undermine structures and cause extensive damage as saturated, unconsolidated sediments are transformed into a substance that acts like a liquid.

Earthquakes are a common cause of liquefaction where loosely packed, water-logged sediments come loose from the intense shaking of the quake. This process is more likely to occur in loose to moderately-saturated granular soils with poor drainage, such as

51 Geotechnical Engineering Bureau: NYS DOT, "Liquefaction Potential of Cohesionless Soils," (April 2007). DOT.NY.GOV <https://www.dot.ny.gov/divisions/engineering/technical-services/technical-services-repository/GDP-9b.pdf>.

52 "Geotechnical Design Manual," NYSDOT (October 1, 2012), https://www.dot.ny.gov/divisions/engineering/technical-services/geotechnical-engineering-bureau/geotech-eng-repository/GDM_Ch-9_Seismic_Design.pdf.

“silty sands or sands and gravels capped or containing seams of impermeable sediments.”⁵³ As shown in Figure 5, every borough of NYC contains the type of geology susceptible to liquefaction with major portions of Manhattan, Brooklyn, and Queens containing significant amounts of soft soils.⁵⁴ These areas deserve special attention when formulating response plans for an earthquake scenario. Other features of seismic hazards unique to the East Coast include lack of surface faulting (potential loci of future quakes are not well known), higher high-frequency content of seismic ground motions to large distance, and higher contrast of shaking on soft soils versus underlying hard rock (high site amplification).⁵⁵ One of the most dangerous consequences of a powerful earthquake is the process of liquefaction.

53 “*Liquefaction Resistance of Soils: Summary Report from the 1996 NCEER and 1998 NCEER/NSF Workshops on Evaluation of Liquefaction Resistance of Soils,*” Journal of Geotechnical and Geoenvironmental Engineering 127 (10): 297–313.

54 “Rock and Soil Types in the Region,” NY / NJ / CT Earthquake Risks and Mitigation, <http://www.nycem.org/techdocs/FinalReport/13rock.pdf>.

55 Geotechnical Engineering Bureau: NYS DOT. “*Liquefaction Potential of Cohesionless Soils,*” (April 2007), DOT.NY.GOV<https://www.dot.ny.gov/divisions/engineering/technical-services/technical-services-repository/GDP-9b.pdf>.

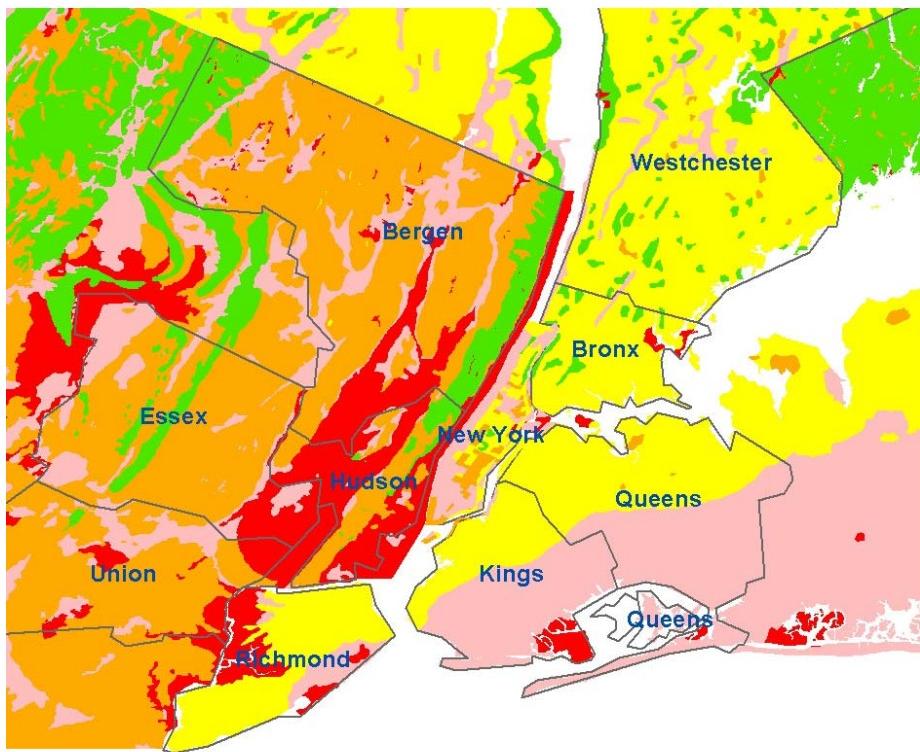


Figure 5. Ground Composition of NYC and Surrounding Areas. (Available at <http://www.nycem.org/techdocs/FinalReport/13rock.pdf>).

NEHRP SOIL CLASSIFICATIONS

- Green: Hard Rock**
- Yellow: Rock**
- Brown: Dense Soil / Soft Rock**
- Pink: Soft Soils**
- Red: Special Soils**

D. TSUNAMI

Most experts believe that the chances are slim that citizens of New York will ever experience a destructive tsunami like the one that struck Japan following their 2011 earthquake. However, Steven Ward, a professor at the University of California Santa Cruz's Institute of Geophysics and Planetary Physics, and his co-author, Simon Day of University College London, released a paper in 2001 detailing the possibility of a tsunami hitting New York as well as the entire eastern coast of the United States. Unlike the

Japanese tsunami, this one could be set off by a catastrophic failure of the west flank of the Cumbre Vieja Volcano in the Canary Islands, off the coast of Africa.⁵⁶ The size of the resulting tsunami will depend on the magnitude of the resultant landslide, and whether it occurs quickly or in phases. Ultimately, Ward anticipates wide swaths of Manhattan, Brooklyn, Long Island, New Jersey and Staten Island to be underwater following this disaster.⁵⁷ Fortunately, even if this event does occur, Americans along the East Coast will most likely be warned thanks to modern monitoring and communication technology, and will have enough time (approximately 9 to 10 hours) to evacuate, saving thousands of lives.⁵⁸

The potential for a tsunami as a result of an earthquake is a different problem altogether. Some geologists warn that there are several active undersea areas, called subduction zones, off of both of America's coasts, which could trigger a massive tsunami. Alaska has been hit repeatedly by these enormous waves, as has Hawaii. Dr. John Rundle, the director of The Center for Computational Science and Engineering at UC Davis, agrees that "the risk for tsunamis....is very real and very present and very possible."⁵⁹ Although Dr. Rundle agrees this event is not likely, he confirms that somewhere in the world, a devastating tsunami has happened "about every 5,000 to 10,000 years."⁶⁰ More likely, however, would be a moderate to severe quake occurring off the coast of, and in proximity to, NYC. This event could trigger a fairly large tsunami close to the major metropolitan area's shores, with little warning to residents, and virtually no reaction time for responders. Current standard operating procedures, and evacuation plans for flood-prone areas in NYC during hurricanes and powerful storms, should be reviewed and possibly expanded to take into account flooding as a result of an earthquake-induced tsunami. To put things into perspective, Table 5 shows the

56 Dan Amira, "Oh, By the Way, an Enormous Tsunami Could Strike New York City," New York (March 15, 2011), http://nymag.com/daily/intel/2011/03/oh_by_the_way_an_enormous_tsun.html.

57 Ibid.

58 Ibid.

59 Edie Magnus, "*Could a Tsunami Hit the U.S.?*" Dateline NBC, (January 9, 2005). http://www.msnbc.msn.com/id/6798858/ns/dateline_nbc/t/could-tsunami-hit-us/.

60 Ibid.

probability of a tsunami occurring within 500 and 5000 years, respectively. The dangers presented by a tsunami striking NYC's coastal areas merit further study and should be part of the FDNY's strategic earthquake response plan.

Table 5. USGS Probability of Earthquake Occurrence for Non-Subduction Zones off of the U.S. Atlantic Coast. (From: U.S. States and Territories National Tsunami Hazard Assessment).⁶¹

State/Territory	Earthquake with Magnitude > 6.5 in 500 years within 50 km of coast	Earthquake with Magnitude > 6.5 in 5000 years within 50 km of coast	Historical maximum magnitude observed near shore or offshore
Maine	<3%	<30%	<6
New Hampshire	<3%	<30%	<6
Massachusetts	<3%	<25%	<6
Rhode Island	<2%	<15%	<6
Connecticut	<2%	<30%	<6
New York	<4%	<30%	<6
New Jersey	<4%	<30%	<6
Delaware	<3%	<15%	<6
Maryland	<2%	<15%	<6
Virginia	<1%	<4%	<6

E. INDIAN POINT NUCLEAR POWER PLANT

NYC is susceptible to an accidental release of radiation from a variety of sources. Universities, colleges and hospitals all contain various radioactive materials, but the

⁶¹ Paula K. Dunbar, Craig S. Weaver, "U.S. States and Territories National Tsunami Hazard Assessment: Historical Record and Sources for Waves," http://nthsmp.tsunami.gov/documents/Tsunami_Assessment_Final.pdf.

dangers posed by these facilities are generally minimal compared to the potential hazards posed by the Indian Point Nuclear Power Plant, just 24 miles north of NYC.⁶² According to a 2011 report, federal watchdogs made safety at the Indian Point Nuclear Power Plant their top priority and New York's Governor stated that he wants the aging nuclear power plant shut down in the midst of its two remaining nuclear reactors being up for recertification in 2013 and 2015.⁶³ The ability of this facility to withstand seismic activity is certainly questionable. The Governor recently met with Nuclear Regulatory Commission (NRC) officials to discuss Indian Point's ability to withstand an earthquake beyond its design limits.⁶⁴ The Indian Point plant, which has had its share of problems in the past including a leaking underground pipe feeding a backup cooling system and a transformer explosion which triggered a brief shutdown, is reportedly designed to withstand an earthquake up to an M 6.1.⁶⁵ That is greater than the most powerful New York quake recorded at M 5.2 in 1884.⁶⁶ More importantly, scientists at Columbia University have discovered that the Indian Point facility is within a mile of where New York's two most active fault lines intersect and a 2008 paper reported the estimated chances of an M 7 earthquake occurring at this intersection to be 1.5% over a 50-year period.⁶⁷ The Columbia paper also noted that Indian Point is located "closer to more people" than any other nuclear plant in America, at one of the least favorable sites from an earthquake hazard and risk perspective.⁶⁸

62 Kenneth Lovett, Richard Sisk, "*Shut Aging Indian Point Nuclear Power Plant Down, Gov. Cuomo Reiterates*," Dailynews.com, (March 23, 2011), <http://www.nydailynews.com/new-york/shut-aging-indian-point-nuclear-power-plant-gov-cuomo-reiterates-article-1.123495>.

63 Ibid.

64 Ibid.

65 Michael Daly, "*Regulators Say Indian Point Nuclear Plant is Safe, but can Chernobyl-on-the-Hudson Happen?*" Dailynews.com (March 15, 2011), <http://www.nydailynews.com/new-york/regulators-indian-point-nuclear-plant-safe-chernobyl-on-the-hudson-happen-article-1.121117>.

66 Ibid.

67 Ibid.

68 Michael Daly, "*Regulators Say Indian Point Nuclear Plant is Safe, but can Chernobyl-on-the-Hudson Happen?*" Dailynews.com (March 15, 2011), <http://www.nydailynews.com/new-york/regulators-indian-point-nuclear-plant-safe-chernobyl-on-the-hudson-happen-article-1.121117>.

Nuclear power has generally proved safe when it comes to human health, but when something goes wrong, it can result in widespread radioactive exposure and health hazards that can turn an average power plant mishap into a disaster reminiscent of Chernobyl.⁶⁹ Radiation is invisible and cannot be tasted, smelled or felt.⁷⁰ There are four primary kinds of ionizing radiation; alpha, beta, gamma and x-ray. Alpha particles are relatively heavy and, when emitted, cannot penetrate human skin or clothing, but are harmful if they get into the body via inhalation, ingestion or other methods.⁷¹ Beta radiation can cause skin injury and is also harmful to the body internally. Gamma and X-rays are high-energy radiation that can damage tissue and are considered the most hazardous to humans.⁷² Concerning the possible spread of radiation from malfunctioning nuclear power plants, most experts anticipate a gradual exposure over time.⁷³ If leaking occurs, the local population could breathe in particles or ingest contaminated foods with radioactive elements causing widespread radiation sickness and death.⁷⁴ An effective earthquake response plan for any area located in proximity to a nuclear power plant must take into account the possibility of significant, widespread, high dose radiation exposure and contamination.

A nuclear meltdown at the Indian Point plant can certainly pose significant hazards to the citizens of NYC, yet dangers of day-to-day activities using radioactive substances cannot be overlooked in the event of an earthquake. A study from the National Council on Radiation Protection and Measurement found that nearly half of the radiation to which the U.S. population is exposed comes from medical sources such as CT scans, X-rays and nuclear medicine.⁷⁵ Prolonged exposure to radiation is dangerous and the

⁶⁹ Elizabeth Landau, Madison Park, “*Radiation: When to Worry*,” CNN.com (March 15, 2011), <http://www.cnn.com/2011/HEALTH/03/14/japan.radiation.sickness/index.html>.

⁷⁰ Ibid.

⁷¹ Ibid.

⁷² Ibid.

⁷³ Ibid.

⁷⁴ Ibid.

⁷⁵ Elizabeth Landau, Madison, Park, “*Radiation: When to Worry*.” CNN.com (March 15, 2011), <http://www.cnn.com/2011/HEALTH/03/14/japan.radiation.sickness/index.html>.

farther away an individual is from the source of radiation, the less exposure that person will have to the damaging radioactive particles or waves.⁷⁶ To this effect, the FDNY has adopted the principles of time, distance and shielding for routine radiological incidents and this policy should be implemented during disaster mitigation following a moderate or severe earthquake. An accidental radiological release which occurs due to an earthquake poses a significant threat to the health and safety of first responders operating at incidents in and around hospitals, universities and other research and healthcare institutions, and should be taken into consideration when assessing the threats to NYC during a seismic event.

⁷⁶ Elizabeth Landau, Madison, Park, “Radiation: When to Worry.” CNN.com (March 15, 2011), <http://www.cnn.com/2011/HEALTH/03/14/japan.radiation.sickness/index.html>.

III. CASE STUDIES

A medium to large earthquake occurring in or around NYC is a high risk, yet low frequency event. As shown in Table 4, an M 6 can result in a total loss of \$39.3 billion for the Tristate area. Compare that to \$5.7 billion in lost gross city product as a result of Hurricane Sandy in 2012.⁷⁷ Because of the low frequency of this event, an abundant amount of data portraying the seismic hazard in NYC is not readily available. Historical records of earthquakes in the New York area cannot be analyzed to determine successful response strategies, as these quakes occurred in a time when the population, buildings and infrastructure of NYC were substantially different than they are today. In order to pre-plan an effective response in the event of this black swan, a case study must be performed analyzing various earthquakes occurring in similar large cities, in a time frame comparable to present day. A review of the challenges faced by modern urban cities in the aftermath of an earthquake, as well as a critique of their emergency response systems, will prove invaluable in determining how to prepare the FDNY for a similar scenario.

A. PORT-AU-PRINCE, HAITI EARTHQUAKE—JANUARY 12, 2010

Port-Au Prince was truly unprepared for the severe tremors of January 12, 2010, and this resulted in mass devastation in the immediate aftermath of the very powerful quake. The city relied heavily on foreign aid and personnel for rescue and recovery and most positive aspects of the relief effort were the result of actions taken by trained international response teams. The logistics involved in importing valuable human resources from America and other countries to the devastated area played a key role in what little success occurred following the disaster. An analysis of the failures that occurred following this disaster will help emergency response planners avoid similar mistakes in their own communities.

⁷⁷ Christopher Brennan, “*Sandy Will Cost New York an Estimated \$19 B., Mayor Wants Feds to Cover Half,*” New York Observer. <http://observer.com/2012/11/sandy-will-cost-new-york-an-estimated-19b-mayor-wants-feds-to-cover-half/>.

Following the massive quake, the Haitian government reported over 200,000 deaths, 300,000 injuries and 1,000,000 left homeless.⁷⁸ The government of Haiti also claimed that 250,000 residential buildings and 30,000 businesses had collapsed or were severely damaged.⁷⁹ Because of the shallow depth of the quake, shaking damage was more severe than for other quakes of similar magnitude. The days following the initial quake, the USGS reported over 50 aftershocks measuring M 4.5 or greater, including an M 5.9 aftershock lasting only seconds but panicking thousands.⁸⁰ A tsunami warning was issued immediately after the initial quake, but subsequently cancelled. Two weeks later, however, it was reported, and later confirmed, that the small fishing town of Petit Paradis was hit by a localized tsunami wave shortly after the earthquake, sweeping three victims out to sea.⁸¹

For days following the earthquake, civilians resorted to sleeping in the streets, automobiles and makeshift shanty towns, either out of fear of aftershocks or because their dwellings had actually been destroyed. Damage was especially excessive due to the low construction standards in Haiti and lack of building codes. Many buildings were built in areas considered hazardous even under normal conditions, with insufficient foundations or steel works. In the aftermath of the quake, police headquarters near the Toussaint L’Ouverture International Airport became Haiti’s base of political operations, although a number of government officials remained trapped in the Presidential Palace.⁸² Further hampering emergency response, many government workers focused on their own missing family members and tended to wounded relatives, leaving the government largely ineffective. Although the president and his remaining cabinet met with United Nations

⁷⁸ “Haiti will not Die, President Rene Preval Insists”. BBC News, (February 12, 2010) <http://news.bbc.co.uk/2/hi/americas/8511997.stm>.

⁷⁹ Clarens Renois (5 February 2010), “*Haitians Angry Over Slow Aid,*” Melbourne: The Age. <http://www.theage.com.au/world/haitians-angry-over-slow-aid-20100204-ng2g.html>.

⁸⁰ Paul Haven, Mike Melia, “Haiti Aftershock: Another Earthquake Near Port-au-Prince,” The Huffington Post. (January 20, 2010). http://www.huffingtonpost.com/2010/01/20/haiti-aftershock_n_429328.html.

⁸¹ “Ten Deadliest Natural Disasters,” Catastrophe Monitor (July 20, 2010), http://www.banjalukaspot.com/catastrophemonitor/public_html/article.php?story=20100720231532118.

⁸² Marc Lacey, Simon Romero, “Government Struggles to Exhume Itself,” The New York Times. (January 15, 2010), <http://www.nytimes.com/2010/01/16/world/americas/16preval.htm>.

(UN) planners daily, there was confusion as to who was in charge and no single group had organized relief efforts as of January 16, 2010.⁸³

Communication systems, hospitals, infrastructure networks and even land, air and sea transport facilities were severely damaged by the earthquake, hampering rescue and aid efforts. The quake seriously damaged the control tower at Toussaint L’Ouverture International Airport as well as Port-au-Prince’s seaport, leaving the harbor unusable for operations.⁸⁴ In addition, air traffic congestion coupled with difficulty in prioritizing incoming flights further complicated initial rescue efforts. Ultimately, control of the local airport was handed over to the United States to hasten and ease air transport operations.⁸⁵ Hospitals throughout Haiti were left incapable of use, leaving many of the injured without proper care. The quake damaged all but one hospital in Port-Au-Prince leaving hundreds desperate for medical attention.⁸⁶ The situation became so desperate that the UN provided an emergency generator for a hospital after discovering surgeries were being performed under candlelight without the use of electric equipment.⁸⁷ Less than one week after the earthquake, a number of hospitals reported having expended their stocks of medical supplies, including antibiotics. The morgues of Port-au-Prince were quickly overwhelmed and a thousand bodies had been placed on the streets with government manned trucks utilized to bury the dead in mass graves. Additionally, above-ground tombs were forced open so bodies could be stacked inside while others were burned. As the rescue portion of the response transformed into relief efforts, supplies, medical care

83 David R. DiOrio, “Operation Unified Response – Haiti Earthquake 2010,” Unified Response Version 1. (November 1, 2010).
http://www.jfsc.ndu.edu/schools_programs/jc2ios/io/student_readings/4A_Haiti_HADR_Case_Study_revNov10.pdf.

84 Eric Lipton, “Devastation, Seen From a Ship,” The New York Times (January 13, 2010),
<http://www.nytimes.com/2010/01/14/world/americas/14cutter.html>.

85 John Crawley, Andrew Quinn, “UPDATE: 1-U.S. Takes Control of Haiti Airport to Speed Aid.” Reuters (January 15, 2010), <http://www.reuters.com/article/2010/01/16/quake-haiti-flights-idUSN1513622820100116>.

86 “Only One Hospital Open in Haiti’s Quake-Hot Capital,” News.com.au (January 14, 2010),
<http://www.news.com.au/breaking-news/only-one-hospital-open-in-haitis-quake-hit-capital/story-e6frfku0-1225819044634>.

87 “UN Provides Generator for a Hospital in Haiti,” Business.UN.ORG
<http://business.un.org/en/documents/341>.

and sanitation became priorities. Long delays in aid distribution brought about widespread frustration from survivors to rescue workers and looting and sporadic violence became commonplace in many areas. Some citizens constructed their own roadblocks to keep out looters while others resorted to vigilantism.

Many government and public buildings were damaged or destroyed including the Palace of Justice, the National Assembly, the Supreme Court and even a prison, allowing 4,000 inmates to escape.⁸⁸ The National Palace was also damaged, with the president and his wife escaping injury.⁸⁹ With no municipal petrol reserves and few city officials with working cell phones even before the quake, communications and transportation became extremely hampered http://en.wikipedia.org/wiki/2010_Haiti_earthquake - cite_note-wp-65#cite_note-wp-65. Considerable damage to Haiti's communications infrastructure left the public telephone system unavailable, and two of Haiti's largest cellular telephone providers, Digicel and Comcel Haiti, had their services disrupted by the earthquake.⁹⁰ Fiber-optic connectivity was damaged knocking radio stations off the air and some 20 of about 50 stations that were active in the capital region prior to the earthquake took about a week to get back "on air."⁹¹

Rescue efforts began immediately following the earthquake, with ambulatory survivors extricating their friends and neighbors from the rubble of collapsed buildings. Rescue work slightly intensified with the arrival of international rescuers, police and military personnel two days after the quake with numerous countries providing aid including rescue teams, medical teams, engineers and support personnel. The neighboring

⁸⁸ Sawer, Patrick, Sherwell, Phili, "Haiti Earthquake: Looting and Gun-Fights Break Out," The Telegraph (January 16, 2010), <http://www.telegraph.co.uk/news/worldnews/centralamericaandthecaribbean/haiti/7005554/Haiti-earthquake-looting-and-gun-fights-break-out.html>.

⁸⁹ Jonathan Katz, "Haiti's President Rene Preval Narrowly Missed Injury in Haiti Earthquake," The Huffington Post (January 19, 2010), http://www.huffingtonpost.com/2010/01/19/haitis-president-rene-pre_n_429167.html.

⁹⁰ "A Life-Saving Case for Applying Interoperable Data Standards to Share Hospital Availability," DHS Science & Technology. Information in Times of an Emergency," <http://markmail.org/download.xqy?id=rhatjsl2jidsg5op&number=1>.

⁹¹ T. Carter Ross (January 25, 2010), "Radio Extends Efforts to Help Haiti," Radio World. <http://www.rwononline.com/article/93612>.

Dominican Republic was the first country to offer assistance to Haiti, contributing clean water, food and heavy machinery, as well as making its hospitals available to the injured. Dominican airports were also made available for support operations. The Dominican Republic helped restore some of Haiti's damaged telephone services and the Dominican Red Cross coordinated early medical relief as the government volunteered mobile medical units, including doctors of diverse specialties. Among the other resources sent to Haiti were trucks carrying canned food, mobile kitchens and cooks capable of producing thousands of meals per day. Other nations, from the United States to Qatar, sent personnel, medicine, material and other much-needed aid. A rescue team sent by the Israel Defense Forces' Home Front Command established a field hospital near the UN building and the USS Carl Vinson arrived from America with relief supplies including 14 helicopters.⁹²

In the end, over 20 countries had sent military personnel to Haiti. Initial rescue efforts were restricted by traffic congestion and debris until U.S. helicopters were brought in to distribute aid to areas impossible to reach by land. The International Charter on Space and Major Disasters was activated, sharing satellite imagery of affected regions with rescue and aid organizations.⁹³ Even social networking websites, such as Facebook and Twitter, played a role in communicating the need for rescue in the aftermath.⁹⁴ Ultimately, it took a vast number of resources and a large part of the international community to mitigate the large earthquake that virtually destroyed Port-Au-Prince. Overall, it can be stated that this was an unsuccessful response by an ill-prepared country and emergency planners should look for ways to avoid repeating the numerous failures which occurred following this disaster.

Failures:

92 Yochi J. Dreazen, "Three-Star General to Head U.S. Relief in Haiti," The Wall Street Journal. (January 15, 2010).<http://online.wsj.com/article/SB10001424052748704281204575003173316615894.html>.

93 Jonathan Amos, "How Satellites are Being Used in Haiti," BBC News (January 14, 2010), <http://www.bbc.co.uk/blogs/thereporters/jonathanamos/2010/01/how-satellites-are-being-used.shtml>.

94 Alice Tarleton, "Twitter Search for Haiti Survivors," Channel 4 News (January 15, 2010), http://www.channel4.com/news/articles/science_technology/twitter+search+for+haiti+survivors+/3503342.html.

- Poor construction standards
- Mediocre infrastructure
- Lack of leadership & direction from government officials
- Danger underestimated (tsunami warning cancelled)
- No pre-plan (body disposal, aide distribution, medical care, back-up command sites)
- Looting/vigilantism
- Poor hospital resiliency
- Transport hubs severely incapacitated
- Hampered communications and lack of communication resiliency

Successes:

- Timely aid on the part of the Dominican Republic and the international community
- International military assistance utilized
- Ocean vessels utilized to distribute large quantities of resources
- Helicopters utilized to bypass damaged roads
- Handing over airport control to the U.S.

B. CHILE EARTHQUAKE—FEBRUARY 27, 2010

The earthquake that occurred in Chile in February 2010, affected a number of cities along the Chilean coast, with most damage centered in Santiago, a large sprawling urban center. Though met by a significantly more effective response than the Port-Au-Prince earthquake, there were still some notable strategic failures. A review of the emergency response to this earthquake, then, is useful in formulating a strategy for responding to quakes affecting numerous populated cities within the same geographic area, as could well be the case along the northeast coast of America.

The 2010 Chile earthquake occurred on February 27, 2010, centered roughly two miles off the coast of central Chile, and was the sixth largest earthquake ever to be recorded by a seismograph. According to the USGS, at least 523 people were killed, 24 missing, about 12,000 injured, 800,000 displaced and at least 370,000 houses,

4,013 schools, 79 hospitals and 4,200 boats damaged or destroyed by the earthquake and associated tsunami.⁹⁵ The epicenter was just off the coast and the resulting tsunami devastated several coastal towns in south-central Chile. Having a magnitude of 8.8, the intense shaking lasted approximately three minutes.⁹⁶ In the time period since the earthquake occurred at least 304 aftershocks M 5 or greater, with 21 of these M 6 or greater, have been recorded.⁹⁷

This was a far-reaching earthquake that affected many cities. After the earthquake struck, most of the deceased were buried under collapsed buildings or trapped inside cars. Buildings collapsed in the populated city of Santiago with power outages in many parts of the city. The city of Concepcion, cut off by damaged infrastructure, reported numerous damaged buildings and fires. A fifteen-story residential building known as “Alto Rio” toppled backwards, landing horizontally on the ground, trapping residents.⁹⁸ Dilapidated buildings could be seen in the city of Temuco, 250 miles from the epicenter. Tsunamis struck a few hours after the quake, washing away entire fishing and beach communities including Constitucion, Curanipe, Pelluhue, and Dichato, and even partially obliterated industrial ports like Talcahuano.⁹⁹ The ensuing tsunami reached as far as Tohoku, Japan, where damage to the fishing industry reached roughly \$66 million. Thousands remained unaccounted for and, in the small town of Constitucion, at least 350 were swallowed by the sea http://en.wikipedia.org/wiki/2010_Chile_earthquake_-_cite_note-71#cite_note-71.¹⁰⁰ In Talca, with many dead trapped in the rubble and the administrative building uninhabitable, authorities had to improvise and set up government functions in the parade

⁹⁵ “Magnitude 8.8 - Offshore Bio-Bio, Chile,” <http://earthquake.usgs.gov/earthquakes/eqinthenews/2010/us2010tfan/#summary>.

⁹⁶ “Science Highlights 2010 - UNAVCO Event Response - Mw=8.8 Chile Earthquake February 27, 2010,” UNAVCO. http://www.unavco.org/community_science/science_highlights/2010/M8.8-Chile.html.

⁹⁷ “Magnitude 8.8 - Offshore Bio-Bio, Chile,” <http://earthquake.usgs.gov/earthquakes/eqinthenews/2010/us2010tfan/#summary>.

⁹⁸ “*Why Were Chile’s Newest Buildings Prone to Destruction?*” Global Post (May 30, 2010), <http://www.globalpost.com/dispatch/chile/100315/building-codes-earthquake>.

⁹⁹ Rene, “Massive Earthquake Shatters Myth of Chilean Exceptionalism: Deep Class Faultlines Exposed,” Solidarity (March 3, 2010), <http://www.solidarity-us.org/site/node/2716>.

¹⁰⁰ Ibid.

ground http://en.wikipedia.org/wiki/2010_Chile_earthquake - cite_note-73#cite_note-73.¹⁰¹ Overwhelmed hospitals attempted to transport patients to Santiago, but were turned back by blocked roads. Chileans living in regions distant from the earthquake, both in Chile and abroad, desperately sought to learn more regarding their family and friends affected by the earthquake as failure of electric cables and destruction of telephone lines hampered communications.

Four hours after the earthquake, when the death count was still low, the Chilean President held a press conference informing viewers of the situation, mistakenly stating that Chile did not need international aid http://en.wikipedia.org/wiki/2010_Chile_earthquake - cite_note-Impulsobaires-96#cite_note-Impulsobaires-96.¹⁰² However, with approximately two million people affected by the earthquake and more than 500,000 houses uninhabitable it became clear that the people of Chile could not handle this disaster on their own. Throughout many urban areas people slept in tents, parks and on streets for fear of aftershocks. The government responded by distributing food and other vital aid to affected areas of the country http://en.wikipedia.org/wiki/2010_Chile_earthquake - cite_note-108#cite_note-108.

The earthquake also caused a blackout affecting 93% of Chile's population, lasting for several days in some locations. http://en.wikipedia.org/wiki/2010_Chile_earthquake - cite_note-12#cite_note-12¹⁰³ Chile's president eventually declared a "state of catastrophe" and deployed the military to take control of most of the affected areas. Three hospitals in Santiago collapsed, and a dozen more south of the capital suffered significant damage.¹⁰⁴ Santiago's International Airport was also badly

101 "Chilean Catastrophic Earthquake of 2010 – 20 Months Later," Instituto Vasovienne of Polish-Chilean Cultural Heritage (October 12, 2011), <http://krzysd-pacific.blogspot.com/2011/10/not-so-sunny-day.html#!/2011/10/not-so-sunny-day.html>.

102 "Chile Quake Damage From Above," CNN. (February 28, 2010), http://wn.com/Chile_quake_damage_from_above.

103 "ICAT Chile: After Action Report," http://emergency.lacity.org/stellent/groups/departments/@emd_contributor/documents/contributor_web_content/lacityp_015617.pdf.

104 "Massive Quake Hits Chile, Triggers Tsunami," MSNBC (February 27, 2010), http://www.msnbc.msn.com/id/35615455/ns/world_news-chile_earthquake/.

damaged, resulting in cancellation all flight operations. Fortunately, by February 28, 2010, some commercial airline services were re-established and allowed to land in Santiago.¹⁰⁵

Although mistakes were made, the government was largely effective in their response. Following the earthquake, almost half of the country was declared a “catastrophe zone” with curfews imposed in areas of looting and public disorder.¹⁰⁶ Looting occurred in places such as supermarkets http://en.wikipedia.org/wiki/2010_Chile_earthquake - cite_note-104#cite_note-104 and stolen goods ranged from necessities such as food to luxuries such as electronic items. As a result, special forces known as “carabineros” were sent to disperse rioters, using tear gas and water cannons http://en.wikipedia.org/wiki/2010_Chile_earthquake - cite_note-101#cite_note-101.¹⁰⁷ Curfews were put in place and arrests were made, but despite these measures, pillaging continued in both urban and rural areas of the affected zones [http://en.wikipedia.org/wiki/2010_Chile_earthquake - cite note-Ya son 723-102#cite note-Ya son 723-102](http://en.wikipedia.org/wiki/2010_Chile_earthquake - cite_note-Ya son 723-102#cite_note-Ya son 723-102). As some neighborhoods began to form their own vigilante groups, legislative measures were adopted by the Chilean government increasing penalties for stealing during a state of catastrophe. In Concepcion, a prison riot began with different parts of the prison set ablaze, but was eventually brought under control with help from military units.

Although mistakes were made, the Chilean government conducted an adequate emergency response. Problems were dealt with as they were recognized and failures corrected in a timely fashion. In this case, a strong central government was able to coordinate a response to a major disaster and many key decisions are worthy of emulation.

105 Jonathan Franklin, Adam Gabbatt, (March 1, 2010), “*Chilean Military Takes Control of Quake-Hit Cities*,” The Guardian (London). <http://www.guardian.co.uk/world/2010/mar/01/chile-military-earthquake-cities-looting>.

106 Jose Luis Saavedra, “Massive Earthquake Hits Chile, 214 Dead.” Reuters (February 27, 2010), <http://www.reuters.com/article/2010/02/27/us-quake-chile-idUSTRE61Q0S920100227>.

107 “Earthquakes In Diverse Places,” The Millenium Grou (May 27, 2010), <http://tmgnow.com/TMG1/2010/05/27/earthquakes-in-deverse-places/>.

Failures:

- No timely solution to assist communities initially isolated from outside assistance
- Failure to initially recognize the magnitude of the disaster
- Failed hospital resiliency
- Looting/vigilantism
- Prison riots

Successes:

- Parade grounds used for initial mustering sights
- Government distribution of food and water
- “State of Catastrophe” declared
- Curfews and special forces utilized to handle public disorder
- Successful use of military
- Increased penalties for crimes during state of emergency
- Successful evacuation for special hazards (chemical plant fire)

C. JAPAN EARTHQUAKE—MARCH 10, 2011

With Tokyo being a large, populated city similar in scale to NYC, including a vast underground subway system, and located in an earthquake-prone zone, there is much to be learned from Japan’s level of earthquake preparedness. Although prepared for large earthquakes and tsunamis in a number of different ways, there were failures in Japan’s emergency response strategy following the M 9 earthquake of March 10, 2011. Failure to anticipate the magnitude and scope of the consequences from this M 9 quake, Japan was plagued by numerous breakdowns in communications between the government and private industry that resulted in destruction far greater than anticipated. In addition, the Fukushima Nuclear Power Plant melt-down diverted emergency response resources to address the overwhelming consequences that a nuclear containment breech would entail. This had far-reaching implications for planning and emergency response strategies of all countries witness to the disaster.

On March 11, 2011, an M 9 undersea earthquake struck off of the coast of Japan with an epicenter approximately 231 miles northeast of Tokyo.¹⁰⁸ Lasting approximately six minutes, it was the most powerful known earthquake to have ever hit Japan, and one of the five most powerful earthquakes in the world since modern record-keeping began.¹⁰⁹ Occurring at a relatively shallow depth of 18.6 miles, the resultant tsunami waves reached heights of 37.88 m at Miyako in Tohoku's Iwate Prefecture, and caused the majority of casualties in Iwate, Miyagi and Fukushima.¹¹⁰ At least 15,703 people were killed, 4,647 missing, 5,314 injured, 130,927 displaced and at least 332,395 buildings, 2,126 roads, 56 bridges and 26 railways were destroyed or damaged as a result of the earthquake and tsunami.¹¹¹ The high death toll resulted from the tsunami, with an estimated 90% of deaths attributed to drowning.¹¹² About 230,000 automobiles and trucks were damaged or destroyed in the quake http://en.wikipedia.org/wiki/2011_T%C5%8Dhoku_earthquake_and_tsunami - cite_note-202#cite_note-202.¹¹³ The damage persisted for some time with approximately 1.9 million households in Japan without electricity three days after the quake and 1.4 million households without water http://en.wikipedia.org/wiki/2011_T%C5%8Dhoku_earthquake_and_tsunami - cite_note-waterfoodheat-30#cite_note-waterfoodheat-30.¹¹⁴⁻¹¹⁵ Hundreds of aftershocks continued to batter the coast of Japan for the next two days following the M 9 earthquake, with

108 "Magnitude 9.0 - Near the East Coast of Honshu, Japan," <http://earthquake.usgs.gov/earthquakes/eqinthenews/2011/usc0001xgp/#details>.

109 "New USGS Number Puts Japan Quake at 4th Largest," CBS News, Associated Press, http://www.cbsnews.com/2100-202_162-20043126.html.

110 "Magnitude 9.0 - Near The East Coast of Honshu, Japan," <http://earthquake.usgs.gov/earthquakes/recenteqsw/Quakes/usc0001xgp.php#summary>.

111 Ibid.

112 Tsuneo Sakai, "Japan Report," International Hospital Federation. <http://www.ihf-fih.org/en/IHF-Newsletters/Articles/May-2011/IHF-News/Special-Japan/Japan-Report>.

113 "Applications to Deregister Cars Lost in Tsunami Soar," The Japan Times (June 16, 2011), <http://www.japantimes.co.jp/text/nn20110616a4.html>.

114 "Millions Of Stricken Japanese Lack Water, Food, Heat," NPR (March 14, 2011), <http://www.npr.org/2011/03/14/134527591/millions-of-stricken-japanese-lack-water-food-heat>.

115 "Japan Earthquake Update," Asianinfo.org. (March 13, 2011). [\(Retrieved August 22, 2012\).](http://www.asianinfo.org/japan_earthquake.htm)

thirty of them measuring more than M 6.¹¹⁶ Following the disaster, Japanese Prime Minister Naoto Kan stated that, " [since the end of World War II] this is the toughest and the most difficult crisis for Japan" http://en.wikipedia.org/wiki/2011_T%C5%8Dhoku_earthquake_and_tsunami - cite note-29#cite note-29.¹¹⁷

As destructive as the earthquake was, the devastation caused by the resulting tsunami was extraordinary. The tsunami warning issued by the Japan Meteorological Agency was the most serious on its warning scale http://en.wikipedia.org/wiki/2011_T%C5%8Dhoku_earthquake_and_tsunami - cite note-93#cite note-93. Unfortunately, tsunami walls at several of the damaged cities were based on much smaller estimated tsunami heights and many people who thought they were on high enough ground to be safe were swept out to sea. At least 101 designated "tsunami evacuation sites" were struck by the wave.¹¹⁸ It is estimated that damage caused by the surging water, though much more localized, was far more deadly and destructive than the actual quake. There were reports of entire towns destroyed by the giant wave, including 9,500 missing in Minamisanriku.¹¹⁹ The tsunami also resulted in a number of nuclear accidents, primarily meltdowns among the reactors at the Fukushima Daiichi Nuclear Power Plant, with at least three nuclear reactors suffering explosions due to built-up hydrogen gas within the outer containment buildings after cooling system failure. As a result, hundreds of thousands of residents in surrounding areas were evacuated. The powerful tsunami ultimately spread throughout the Pacific Ocean region reaching as far as the coasts of North and South America from Alaska to Chile http://en.wikipedia.org/wiki/2011_T%C5%8Dhoku_earthquake_and_tsunami - cite note-95#cite note-95.

116 Tania Branigan, "Japan Earthquake Aftershocks Threaten Survivors," The Guardian. (March 13, 2011), <http://www.guardian.co.uk/world/2011/mar/13/japan-earthquake-aftershocks-threaten-survivors>.

117 "Japanese PM: 'Toughest' Crisis Since World War II," (CNN. March 13, 2011), <http://edition.cnn.com/2011/WORLD/asiapcf/03/13/japan.quake/index.html?iref=NS1>.

118 Kyodo News, "Tsunami Hit More Than 100 Designated Evacuation Sites," Japan Times, (April 14, 2011), 1, <http://www.japantimes.co.jp/text/nn20110414a4.html>.

119 "8.9-Magnitude Quake Triggers Devastating Japan Tsunami," The People's Forum, <http://www.the-peoples-forum.com/cgi-bin/readart.cgi?ArtNum=23146&Disp=23&Trace=on>.

Unfortunately, in earthquake-prone Japan, only about half of the people located in the coastal areas of Iwate, Miyagi and Fukushima prefectures heeded tsunami warnings immediately after the quake. Of the 13,135 fatalities recovered by April 11, 2011, it is estimated that 92.5% were victims of drowning and those 60 or older accounted for 65.2% of the deaths, with 24% being in their 70s http://en.wikipedia.org/wiki/2011_T%C5%8Dhoku_earthquake_and_tsunami - cite note-163#cite note-163.¹²⁰

Approximately 100,000 children were uprooted from their homes, some of whom were separated from their families because the quake occurred during the school day http://en.wikipedia.org/wiki/2011_T%C5%8Dhoku_earthquake_and_tsunami - cite note-165#cite note-165.¹²¹ Google Person Finder, also used in the Haitian, Chilean and Christchurch, New Zealand earthquakes, was used to collect information about survivors and their locations.¹²²

The earthquake and tsunami ultimately resulted in an estimated 24 million tons of rubble and debris in the three hardest-hit prefectures.¹²³ In north-eastern Japan there were fires in many areas, heavy damage to roads and railways, and at least one dam collapse. Approximately three hundred hospitals with 20 beds or more in Tohoku were damaged, with 11 completely destroyed http://en.wikipedia.org/wiki/2011_T%C5%8Dhoku_earthquake_and_tsunami - cite note-199#cite note-199.¹²⁴ Traditional Japanese funerals, oftentimes elaborate Buddhist ceremonies utilizing cremation, were unable to occur as the thousands of bodies exceeded the capacity of available

120 Steve Beerman, "We Will Not Forget this is the 6 Month Anniversary of the March 11th, 2011 Earthquake and Tsunami in Japan," International Lifesaving Federation, (September 12, 2011), <http://www.ilsf.org/news/articles/we-will-not-forget-6-month-anniversary-march-11th-2011-earthquake-and-tsunami-japan>.

121 Justin McCurry, "Japan Earthquake: 100,000 Children Displaced, Says Charity." (March 15, 2011). The Guardian (London), <http://www.webcitation.org/5xD8JCtef>.

122 "Google Person Finder for Japan Earthquake/Tsunami Launched," PC World, <http://www.pcworld.in/news/google-person-finder-japan-earthquaketsunami-launched-46662011>.

123 Setsuko Kamiya, "Debris Removal, Recycling Daunting, Piecemeal Labor," Japan Times. (June 30, 2011). <http://www.japantimes.co.jp/news/2011/06/30/national/debris-removal-recycling-daunting-piecemeal-labor/>.

124 Kyodo News, "Applications to Dereister Cars Lost in Tsunami Soar," Japan Times, <http://www.japantimes.co.jp/text/nn20110616a4.html>.

crematoriums and morgues, many already damaged. Additionally, shortages of kerosene for cremation, and dry ice for preservation, further prohibited these ceremonies http://en.wikipedia.org/wiki/2011_T%C5%8Dhoku_earthquake_and_tsunami - cite_note-allen20110324-182#cite_note-allen20110324-182. Many bodies were disposed of in hastily-dug mass graves with little or no rites and the promise of cremation in the future.

The rescue operation itself was not without difficulties. The prevalence of safe operations deserves to be questioned as three Japanese Ground Self-Defense Force members died while conducting relief operations in Tohoku http://en.wikipedia.org/wiki/2011_T%C5%8Dhoku_earthquake_and_tsunami - cite_note-191#cite_note-191.¹²⁵ By April 30, 2011, 18 deaths and 420 injuries were attributed to disaster recovery or clean-up efforts http://en.wikipedia.org/wiki/2011_T%C5%8Dhoku_earthquake_and_tsunami - cite_note-193#cite_note-193.¹²⁶

Around 4.4 million households served by Tohoku Electric Power Company (TEPCO) in northern Japan were left without electricity http://en.wikipedia.org/wiki/2011_T%C5%8Dhoku_earthquake_and_tsunami - cite_note-217#cite_note-217.¹²⁷ Additionally, several nuclear and conventional power plants went offline after the earthquake, reducing TEPCO's total capacity and necessitating rolling blackouts. These blackouts of approximately three-hour blocks, which even affected Tokyo, were continued throughout April and May while TEPCO scrambled to find a temporary power solution http://en.wikipedia.org/wiki/2011_T%C5%8Dhoku_earthquake_and_tsunami - cite_note-221#cite_note-221.¹²⁸ The earthquake and tsunami resulted in shortages of food, water, shelter, medicine and fuel for survivors. One year after the quake the Japanese government contributed 1,331 deaths to situations indirectly

125 “GSDF Relief-Duty Sergeant, 27, Dies,” The Japan Times. (May 28, 2011), <http://www.japantimes.co.jp/text/nn20110528a9.html>.

126 Jiji Press, “Disaster Reconstruction Work has Claimed 18 Lives So Far,” Japan Times, <http://www.japantimes.co.jp/text/nn20120606a2.html>.

127 Tsuyoshi Inajima, Yuji Okada, “Japanese Quake Forces Evacuation Near Nuclear Reactor; Oil Refinery Burns,” (March 11, 2011), <http://www.bloomberg.com/news/2011-03-11/cosmo-oil-refinery-set-on-fire-nuclear-power-reactors-shut-by-earthquake.html>.

128 “The Unfolding Crisis in Japan and What It Means to Energy,” Oilonline.com (March 18, 2011), <http://www.oilonline.com/default.asp?id=259&nid=18653>.

related to the earthquake, such as harsh living conditions following the disaster http://en.wikipedia.org/wiki/2011_T%C5%8Dhoku_earthquake_and_tsunami - cite_note-192#cite_note-192.¹²⁹

The rolling blackouts had a profound effect on the rail networks around Tokyo. This led to severe slowdowns within the capital, as long lines at train stations prohibited citizens from getting to work or home. All railway services were initially suspended in Tokyo following the earthquake, leaving approximately 20,000 people stranded at stations throughout the major city.¹³⁰ Fortunately, most Tokyo area train lines resumed full service by the next day, with some services resuming just hours after the earthquake. All of Japan's ports were closed for a brief period following the earthquake, though ports in Tokyo and areas further south were soon re-opened. Japan's transportation network suffered extensive disruption and many sections of the Tohoku Expressway serving northern Japan were damaged and did not reopen to the general public for nearly two weeks.¹³¹ Sendai Airport was entirely underwater due to the tsunami after the initial quake, causing extensive damage, and Tokyo's Narita airport was closed for about six hours, necessitating airborne planes to be diverted to other airports to ensure safe landing http://en.wikipedia.org/wiki/2011_T%C5%8Dhoku_earthquake_and_tsunami - cite_note-AVH1-98#cite_note-AVH1-98.¹³²

Further complicating emergency response, cellular and landline phone services suffered major disruptions http://en.wikipedia.org/wiki/2011_T%C5%8Dhoku_earthquake_and_tsunami - cite_note-288#cite_note-288. Fortunately, Internet services were largely unaffected in areas that were not severely damaged by the quake, as these systems were able to reroute around affected segments onto redundant links.

129 Kyodo News, “Illness, Suicides Drive Up Disaster-Linked Toll,” Japan Times, <http://www.japantimes.co.jp/text/nn20120304a3.html>.

130 “Japan Earthquake Update,” Asioninfo.org (March 13, 2011), http://www.asianinfo.org/japan_earthquake.htm.

131 Kathleen Chu, Sachiko Sakamaki, “Highway to Japan Quake Area Opens as Casualties Pass 25,000,” (March 24, 2011), Bloomberg Businessweek. <http://www.webcitation.org/5xQW5ujha>.

132 “News: Tsunami Rolls through Pacific, Sendai Airport Under Water, Tokyo Narita Closed, Pacific Region Airports Endangered,” Avherald.com (July 6, 2001), <http://avherald.com/h?article=43928907&opt=0>.

Several Wi-Fi hotspot providers provided free access to their networks, while foreign telecommunications and VoIP companies offered free calls to, and in some cases, from, Japan for a limited time. As this particular earthquake resulted in serious damage to an extremely wide range of areas, Japanese broadcasters suspended usual programming to provide continuing coverage of the disaster. Warnings were broadcasted in up to five different languages and Japanese sign language was used at press conferences related to the earthquake and tsunami.¹³³

Many actions on the part of government and private business were successful following the massive earthquake. Japanese Self-Defense Forces, assisted by the international community, sent search and rescue teams to help search for survivors and the Japanese Red Cross reported millions in donations. Private companies helped in the recovery efforts with three steel manufacturers in the Kanto region contributing electricity produced by their in-house conventional power stations to TEPCO for distribution to the general public.¹³⁴ In May following the quake, auto and auto parts makers in Kanto and Tohoku agreed to operate their factories on Saturdays and Sundays but close on Thursdays and Fridays to assist in alleviating the electricity shortage during the summer of 2011 http://en.wikipedia.org/wiki/2011_T%C5%8Dhoku_earthquake_and_tsunami - cite_note-226#cite_note-226.¹³⁵

Much of the media coverage of this massive earthquake was focused on the well-known Fukushima Daiichi crisis. A report from an independent panel stated that the nuclear emergency at the Fukushima Daiichi plant was a “profoundly man-made disaster,” the result of poor earthquake-safety planning and faulty post-tsunami

133 “First Interpreting at Government Press Conference on Disaster,” Deaf News Japan (March 20, 2011), <http://deafjapan.blogspot.com/2011/03/first-interpreting-at-government-press.html>.

134 NHK, “Steel Makers Provide TEPCO with Electricity,” (April 26, 2011), <http://www.icis.com/heren/articles/2011/04/26/9454832/lng/lmd/nippon-steel-to-sell-excess-power-to-tepcos-tohoku.html>.

135 Hiroko Nakata, “*Auto Industry Agrees to Adopt Weekend Work Shifts*,” Japan Times, (May 20, 2011), <http://www.japantimes.co.jp/text/nb20110520a1.html>.

communication.¹³⁶ Not surprisingly, TEPCO's in-house panel claimed the nuclear crisis was unforeseeable, spurred by a giant, unimaginable tsunami. The report suggests that the M 9 earthquake itself may also have caused critical damage that led to the series of meltdowns, arguing facilities should have been made more quake-proof. It is believed that lax safety measures and a conformist culture allowing operation with little scrutiny were also to blame, as early warnings from outside watchdog groups regarding the significant safety risk posed by earthquakes went unheeded.¹³⁷ Results of the investigation also found TEPCO's disaster response manuals to be out-of-date and missing key diagrams.¹³⁸

Government and TEPCO employees were ultimately guilty of not foreseeing or preparing for the black swan. The report stated that the Nuclear and Industrial Safety Agency (NISA) did not press TEPCO to prepare for the loss of main and backup power (i.e., a full station blackout) because the "probability was small."¹³⁹ Slow and faulty communication on the part of TEPCO and government officials after the disaster hampered the emergency response, ultimately resulting in significant radiation spread across 700 square miles of land.¹⁴⁰ Actions following the quake were ineffective as TEPCO was too slow in relaying information to the government and the prime minister's office waited too long to declare a state of emergency. Unaware of the severity of the situation, the prime minister traveled to the plant mid-meltdown and according to the report, "diverted the attention and time of the on-site operational staff and confused the line of command."¹⁴¹

¹³⁶ Chico Harlan, "New Report Blasts Japan's Preparation for, Response to Fukushima Disaster," Washington Post (July 5, 2012), http://www.washingtonpost.com/world/new-report-blasts-japans-preparation-for-response-to-fukushima-disaster/2012/07/05/gJQAN1OEPW_story.html.

¹³⁷ Ibid.

¹³⁸ Ibid.

¹³⁹ Chico Harlan, "New Report Blasts Japan's Preparation for, Response to Fukushima Disaster," Washington Post (July 5, 2012), http://www.washingtonpost.com/world/new-report-blasts-japans-preparation-for-response-to-fukushima-disaster/2012/07/05/gJQAN1OEPW_story.html.

¹⁴⁰ Ibid.

¹⁴¹ Ibid.

The lack of communication and failure to prepare for the “worst-case” scenario were factors hindering an effective response from an otherwise very prepared country. As a nation familiar with devastating earthquakes and tsunamis, one can only hope future leaders will heed the warnings produced by this catastrophe and establish new and improved ways of adequately preparing for the seemingly inevitable and unforeseeable. Emergency managers of NYC should likewise learn the lessons from this disaster and recognize the possibility of the unimaginable occurring at home.

Failures:

- Failure of communities to heed tsunami warnings in many cases
- Failure to build tsunami walls to protect against a “worst-case” tsunami threat
- Poor education and planning regarding earthquakes/tsunamis in some cities (particularly among the elderly and very young)
- Rescuer fatalities
- Casualties resulting from poor follow-up after the initial disaster
- Failure of proper government oversight of safety at Fukushima Daiichi
- Breakdown of communication between government and nuclear facility personnel
- Lack of timely, accurate communication regarding the radioactive threat

Successes:

- Rolling blackouts to ensure continuation of service
- Internet redundancy
- Government response to the initial disaster
- Extensive private industry assistance
- Use of public broadcasting to disseminate information regarding the disaster
- Fairly quick restoration of services in Tokyo
-

D. CHRISTCHURCH, NEW ZEALAND EARTHQUAKE—FEBRUARY 22, 2011

Christchurch, New Zealand is a coastal, populated city that experienced a strong earthquake subsequently identified as the second worst disaster in New Zealand’s history. This case study offers overwhelmingly positive aspects of modern-day response capabilities following the aftermath of a seismic event. Both the government and its citizens provided orderly, systematic assistance in the form of resources, economic aid and personnel. Out of all of the scenarios described herein, the strategies employed following this large disaster are a model for any city facing a potential black swan.

Although smaller in magnitude than New Zealand’s previous quake in 2010, the Christchurch Earthquake was actually more damaging as the epicenter was located closer to the population. It was also closer to the surface, measuring just three miles underground (the 2010 quake was approximately six miles deep) and many buildings in the affected area had already been weakened from previous quakes.¹⁴²¹⁴³ Further complicating the hazard, the earthquake occurred during lunchtime on a busy weekday. Liquefaction caused the upwelling of more than 180,000 tons of silt resulting in significant ground movement that undermined foundations and destroyed infrastructure.¹⁴⁴ It has been stated that damage caused by the Christchurch quake “may be the greatest ever recorded anywhere in a modern city.”¹⁴⁵

According to one seismic engineer, the force of the earthquake was “statistically unlikely” to occur more than once in 1000 years, with intensity greater than many

142 “Deadly Quake Could be Sign of More to Come,” NZ Herald (APN) (February 22, 2011), http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=10708072.

143 “New Zealand Hit by Strong Quake, 65 Dead,” CBC News (Canada: CBC Radio) (February 22, 2011), <http://www.cbc.ca/news/world/story/2011/02/21/new-zealand-quake.html>.

144 “Christchurch Quake Press Conference Monday Morning,” TV3 (February 28, 2011), <http://www.3news.co.nz/VIDEO-Christchurch-quake-press-conference-Monday-morning/tabid/423/articleID/200207/Default.aspx>.

145 New Zealand Society for Earthquake Engineering, “Christchurch Earthquake – an Overview,” Fact Sheet. Institution of Professional Engineers of New Zealand (March 4, 2011), <http://www.ipenz.org.nz/ipenz/forms/pdfs/ChChFactSheets-Overview.pdf>.

modern buildings were designed to withstand.¹⁴⁶ In Christchurch, New Zealand's stringent building codes limited the effects of the quake, but even that was not enough to protect its citizens. New Zealand building codes required a building with a 50 year life-span to withstand predicted loads of a 500 year event.¹⁴⁷ Unfortunately, initial reports suggested a ground motion exceeded that associated with 2500 year design motions.¹⁴⁸ There were over 180 deaths attributed to this earthquake with most due to the collapse of structures, or parts of structures, following the quake. Roughly half of the fatalities occurred in the Canterbury Television building alone.¹⁴⁹ Fatalities occurred across the city, including the surrounding suburbs, with some of the recovered bodies unidentified due to the nature of sustained injuries. A series of aftershocks followed the M 6.1 Canterbury earthquake causing further damage and liquefaction in already weakened areas, with one M 5.2 quake striking the Christchurch region three months after the initial event, further cutting power and causing damage to already weakened buildings in the city center.¹⁵⁰

Many challenges were encountered following the quake. Extensive road and bridge damage hampered rescue efforts. Soil liquefaction and surface flooding forced dramatic road upheavals, spewing water and sand. Cars were crushed by debris and buses destroyed by fallen buildings. Eight people were killed when masonry collapsed onto Red Bus number 702 on Colombo Street.¹⁵¹ As the earthquake struck around lunchtime, some victims on open pavements were buried by collapsed buildings. It was also estimated that

146 Matthew Dearnaley. "Christchurch Earthquake: Wrecker's Tip for Leaning Tower," New Zealand Herald (APN Holdings) (February 25, 2011), http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=10708582.

147 "No Structure Built to Take It," The Gisborne Herald (March 5, 2011), <http://www.gisbornerherald.co.nz/article/?id=21722>.

148 Ibid.

149 "Christchurch & Canterbury." Lonely Planet Publications Pty Ltd. <http://media.lonelyplanet.com/shop/pdfs/24-christchurch-cant-nzl16.1.pdf>. (Retrieved August 22, 2012.).

150 Adonai. "Magnitude 5.2 Earthquake Struck 10 km Off the Coast of Christchurch, New Zealand." The Watchers. (May 25, 2012). <http://thewatchers.adorraeli.com/2012/05/25/magnitude-5-2-earthquake-struck-10-km-off-christ-church-new-zealand/>. (Retrieved August 21, 2012).

151 "List of Deceased – Christchurch Earthquake." New Zealand Police. (September 8, 2011). <http://www.police.govt.nz/list-deceased>. (Retrieved August 17, 2012).

80% of the water and sewer system was severely damaged with authorities not only urging residents to conserve water, but even to collect rainwater.¹⁵² Additionally, by 5 pm on the day of the quake, approximately 80% of the city had no power. Fortunately, forward thinking and various forms of preparation reduced the impact of this devastating quake. Damage occurred in a majority of buildings; particularly those with unreinforced masonry, built before local earthquakes codes were introduced. Newer buildings, such as skyscrapers built within the past twenty to thirty years, performed well compared to older buildings http://en.wikipedia.org/wiki/2011_Christchurch_earthquake - cite note-Cumming5-155#cite_note-Cumming5-155. Christchurch Hospital, though partially evacuated due to damage, remained open throughout the aftermath to treat the injured.¹⁵³

A State of Emergency Level 3 was declared, the highest possible in a regional disaster for New Zealand. Fortunately, the most severe shaking lasted only about 12 seconds, limiting, to some extent, the damage http://en.wikipedia.org/wiki/2011_Christchurch_earthquake - cite note-HERA-38#cite_note-HERA-38.¹⁵⁴ The last survivor was pulled from the rubble the day after the quake though rescue efforts continued for over a week.¹⁵⁵ Of the 3,000 buildings inspected within the center of the city after the initial response, 45% had been given red or yellow stickers to restrict access because of safety concerns http://en.wikipedia.org/wiki/2011_Christchurch_earthquake -

152 Charles Clifton. "The Christchurch Feb 22nd Earthquake: A Personal Report." New Zealand Heavy Engineering Research Association. http://www.hera.org.nz/Story?Action=View&Story_id=1398. (Retrieved August 22, 2012).

153 "Christchurch Quake at a Glance." Stuff. (March 3, 2011). <http://www.stuff.co.nz/national/christchurch-earthquake/4698487/Christchurch-quake-at-a-glance>. (Retrieved August 16, 2012).

154 Charles Clifton. "The Christchurch Feb 22nd Earthquake: A Personal Report." New Zealand Heavy Engineering Research Association. http://www.hera.org.nz/Story?Action=View&Story_id=1398. (August 22, 2012).

155 John Hartevelt. "Machines Signal End of Christchurch Earthquake Rescue." (March 4, 2011). stuff.co.nz. <http://www.stuff.co.nz/national/christchurch-earthquake/4730021/Machines-signal-end-of-Christchurch-earthquake-rescue>. (Retrieved August 19, 2012).

[cite_note-117#cite_note-117](#).¹⁵⁶ In the end, one thousand buildings within the city were slated for demolition because of damage sustained.¹⁵⁷

The Christchurch earthquake is an example of an effective response. Naturally, in the immediate moments following the quake, rescue efforts were performed by ordinary citizens as well as on-duty emergency service personnel. Many hours passed before a full assessment of the devastation could be realized, yet a full emergency management structure was in place within two hours, with national coordination operated from the National Crisis Management Center bunker in the Beehive in Wellington http://en.wikipedia.org/wiki/2011_Christchurch_earthquake - [cite_note-48#cite_note-48](#).¹⁵⁸ Additionally, a regional emergency operations command was established in the Christchurch Art Gallery, a modern earthquake-resistant building that had sustained only minor damage.¹⁵⁹

As per established protocols in New Zealand's Coordinated Incident Management System, the Civil Defense Agency took the role of lead agency, supported by New Zealand's police, fire service and other necessary agencies and organizations http://en.wikipedia.org/wiki/2011_Christchurch_earthquake - [cite_note-52#cite_note-52](#).¹⁶⁰ New Zealand's Defense Forces were called in to assist evacuation as Christchurch's police force was strengthened by a number of international police forces, including approximately 300 Australian police sworn in on their arrival http://en.wikipedia.org/wiki/2011_Christchurch_earthquake - [cite_note-59#cite_note-59](#).

156 "Painstaking Work Continues at Devastated Buildings." Radio New Zealand. (March 4, 2011). <http://www.radionz.co.nz/news/canterbury-earthquake/69902/painstaking-work-continues-at-devastated-buildings>. (Retrieved August 17, 2012).

157 Simon Collins. "Insurance Too Little for Many Firms to Rebuild." The New Zealand Herald. (April 30, 2011). http://www.nzherald.co.nz/christchurch-earthquake/news/article.cfm?c_id=1502981&objectid=10722381. (Retrieved August 21, 2012).

158 John Key. "John Key Reflects on New Zealand's Darkest Day." (February 17, 2012). Stuff.co.nz. <http://www.stuff.co.nz/the-press/news/christchurch-earthquake-2011/12-51/that-day/6409746/John-Key-reflects-on-New-Zealand-s-darkest-day>. (Retrieved August 22, 2012).

159 "In Remembrance." The Fox's Den. (April 9, 2012). <http://thefoxden.chromiumyeti.com/?tag=christchurch>. (Retrieved August 23, 2012).

160 "National State of Emergency Extended." ONE News (TVNZ). (March 7, 2011). <http://tvnz.co.nz/national-news/national-state-emergency-extended-4047979>. (Retrieved August 23, 2012).

59.¹⁶¹ Police duties included general security, evacuations, search and rescue support, traffic control and looting prevention. The police force was also beneficial in providing forensic analysis and evidence gathering for victim identification, working closely with pathologists, forensic scientists and coroners [http://en.wikipedia.org/wiki/2011_Christchurch_earthquake - cite note-Police2M-60#cite note-Police2M-60](http://en.wikipedia.org/wiki/2011_Christchurch_earthquake_-_cite_note-Police2M-60#cite_note-Police2M-60). They were aided by Disaster Victim Identification (DVI) teams from Australia, the UK, Thailand, Taiwan and Israel [http://en.wikipedia.org/wiki/2011_Christchurch_earthquake - cite note-Police2M-60#cite note-Police2M-60](http://en.wikipedia.org/wiki/2011_Christchurch_earthquake_-_cite_note-Police2M-60#cite_note-Police2M-60).¹⁶² Following international best practices after disasters, investigations were detailed and thorough, allowing for an organized system of identification and notification.

Search and rescue after the disaster was accomplished by New Zealand's fire service along with international USAR teams from New Zealand, Australia, the UK, the U.S., Japan, Taiwan, China and Singapore. USAR team members totaled about 150 personnel from New Zealand and 429 from overseas http://en.wikipedia.org/wiki/2011_Christchurch_earthquake - cite_note-Stone-53#cite_note-Stone-53.¹⁶³ Firefighters responded to fires, damaged buildings and landslides and operations were effectively conducted in collaboration with structural engineers, seismologists, geologists, construction workers, crane operators and demolition experts. The U.S. sent USAR California Task Force 2, a 74-member rescue team consisting of rescuers, doctors, engineers and over 25 tons of pre-packaged rescue

¹⁶¹ Max Blenkin. "Australian Police to Aid NZ Quake Recovery." The Sydney Morning Herald. (February 25, 2011). <http://news.smh.com.au/breaking-news-national/australian-police-to-aid-nz-quake-recovery-20110225-1b8b1.html>. (Retrieved August 4, 2012).

¹⁶² "Thai DVI Team Arrives to Assist in Identifying Christchurch Quake Victims." New Zealand Police. (March 2, 2011). <http://www.police.govt.nz/news/release/27340.html>. (Retrieved August 23, 2012).

¹⁶³ Derek Cheng. "Christchurch Earthquake: Search Teams Leaving No Stone Unturned." New Zealand Herald (APN Holdings). (February 28, 2011). http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=10709161. (Retrieved August 23, 2012).

equipment.¹⁶⁴⁻¹⁶⁵ Triage stations were set up and a coordinated medical response was established quickly following the earthquake. The Canterbury District Health Board coordinated health and medical support across the city, cancelling elective surgery and outpatient procedures, and moving existing patients from crowded hospitals to other centers. The board successfully managed infection control following the quake, an area often overlooked in the aftermath of a large disaster. To put this issue into perspective it should be noted that following the Port-au-Prince, Haiti earthquake, a 7-month study by an Israeli-based primary healthcare clinic in Leogane found that 43% of persons presented with an infectious disease, most commonly respiratory tract infections, sexually transmitted diseases and soft tissue infections.¹⁶⁶ Additionally, almost two years after the quake in Haiti, more than half a million people became ill with cholera resulting in more than 7,000 deaths.¹⁶⁷

In New Zealand, primary care facilities, general practice offices and even pharmacies were managed to ensure city-wide medical coverage. Additionally, evacuees from damaged elderly institutions and disabled-care facilities were relocated to other regions. The initial medical care providers were supported by medical staff from areas throughout New Zealand and within a few days, an Australian field hospital providing 75 beds was brought in.¹⁶⁸ The field hospital was set up to treat those injured in the eastern suburbs and was equipped to provide triage, general practice, emergency care,

164 "LA Search-Rescue Heads to Site of NZ Quake." KABC. (February 22, 2011). http://abclocal.go.com/kabc/story?section=weather/earthquake_center&id=7974176. (Retrieved August 24, 2012).

165 "LA County Team Preps for Deployment to New Zealand." NBC Los Angeles. (February 22, 2011). <http://www.nbclosangeles.com/news/local-beat/Los-Angeles-Fire-Department-New-Zealand-116679674.html>. (Retrieved August 24, 2012).

166 Clive Kazura Brown, Jonathan James Rip. "Perspectives on Haiti Two Years after the Earthquake." The American Journal of Tropical Medicine and Hygiene (January 1, 2012). <http://www.ncbi.nlm.nih.gov/pmc/articles/PMC3247098/> (Retrieved February 2, 2013).

167 Donna Leinwand Leger, "Cholera Cripples Haiti, Two Years after Quake." USA Today (January 8, 2012). <http://usatoday30.usatoday.com/news/world/story/2012-01-05/haiti-cholera-outbreak/52419464/1> (Retrieved February 2, 2013).

168 Tim Dick. "Patients Flock to Australian Temporary Hospital." Sydney Morning Herald (Fairfax). (February 27, 2011). <http://www.smh.com.au/world/patients-flock-to-australian-temporary-hospital-20110226-1b97f.html>. (Retrieved August 22, 2012).

maternity and even dentistry http://en.wikipedia.org/wiki/2011_Christchurch_earthquake - cite_note-93#cite_note-93. Additionally, Australia sent counselors and a disaster medical assistance team comprised of emergency and surgical personnel http://en.wikipedia.org/wiki/2011_Christchurch_earthquake - cite_note-92#cite_note-92.

Fundraising and volunteer centers were established throughout the country, with individuals and community groups providing food and services to Christchurch for welfare and clean up. This was a major contributing factor in restoring quality of life and day-to-day services in a timely manner. The volunteer effort was properly controlled and coordinated, with notable results including the removal of thousands of tons of liquefaction silt http://en.wikipedia.org/wiki/2011_Christchurch_earthquake - cite_note-101#cite_note-101. A multitude of businesses and organizations contributed to the rescue, recovery and repair of damaged infrastructure following the quake. Christchurch's electric distribution lines company, Orion, was assisted by other lines companies in New Zealand in the timely restoration of power. As 66 kV underground transmission cables supplying substations were damaged beyond repair, a temporary 66 kV overhead line was set up. Taking six or seven weeks to do so under normal conditions, this emergency line was completed in less than three days http://en.wikipedia.org/wiki/2011_Christchurch_earthquake - cite_note-95#cite_note-95.¹⁶⁹ Power was restored to 82% of households within five days http://en.wikipedia.org/wiki/2011_Christchurch_earthquake - cite_note-96#cite_note-96, and to 95% within two weeks.¹⁷⁰ http://en.wikipedia.org/wiki/2011_Christchurch_earthquake - cite_note-Mathewson-97#cite_note-Mathewson-97.¹⁷¹ A number of emergency generators were

169 "Power Transformer to be Installed in Eastern Chch suburbs." Newstalk ZB (TVNZ). (March 1, 2011). <http://tvnz.co.nz/national-news/power-transformer-installed-in-eastern-chch-suburbs-4042662>. (Retrieved August 21, 2012).

170 "Christchurch Earthquake: Power restored to 82 Percent of Customers." Star Canterbury (APN Holdings). <http://www.starcanterbury.co.nz/local/news/christchurch-earthquake-power-restored-82-percent-/3942263/>. (Retrieved August 20, 2012).

171 Nicole Mathewson. "Power Restored to Most Households." The Press. (March 5, 2011). <http://www.stuff.co.nz/national/christchurch-earthquake/4734825/Power-restored-to-most-households>. (Retrieved August 20, 2012).

donated and telephone companies established emergency communications and allowed free calls. Private companies used milk tankers to bring in fresh water while contractors were working on water supply lines and the military provided desalination plants as bottled water was donated by volunteers and companies. Within one week water mains again supplied up to 70% of households http://en.wikipedia.org/wiki/2011_Christchurch_earthquake - cite_note-98#cite_note-98.¹⁷² Emergency latrines were set up to compensate for damaged sewage lines and over 2000 portable toilets from throughout New Zealand and overseas were brought in http://en.wikipedia.org/wiki/2011_Christchurch_earthquake - cite_note-Mathewson-97#cite_note-Mathewson-97.¹⁷³ Community laundries were established and portable shower units utilized in affected suburbs http://en.wikipedia.org/wiki/2011_Christchurch_earthquake - cite_note-Mathewson-97#cite_note-Mathewson-97. A number of private companies also assisted with transport, particularly Air New Zealand, who operated extra flights to move people and supplies into and out of Christchurch http://en.wikipedia.org/wiki/2011_Christchurch_earthquake - cite_note-100#cite_note-100.¹⁷⁴

With proper leadership, a firm commitment to community, a well-thought-out strategy, and the generosity of a number of private and public organizations, the citizens of Christchurch recovered from this devastating event safely and quickly. This response is truly a model to be emulated by communities following any major disaster. An experienced international USAR team member who participated in the rescue effort described the Christchurch earthquake response as “the best-organized emergency” he

172 “Long Wait for Some Without Power, Water.” Radio New Zealand News. (March 2, 2011). <http://www.radionz.co.nz/news/canterbury-earthquake/69650/long-wait-for-some-without-power,-water>. (Retrieved August 20, 2012).

173 Nicole Mathewson. “Power Restored to Most Households.” The Press. (March 5, 2011). <http://www.stuff.co.nz/national/christchurch-earthquake/4734825/Power-restored-to-most-households>. (Retrieved August 23, 2012).

174 “Air New Zealand Puts on Extra Flights from Christchurch.” National Business Review. (February 23, 2011). <http://www nbr.co.nz/article/air-new-zealand-puts-extra-flights-christchurch-ne-86701>. (Retrieved August 24, 2012).

had witnessed http://en.wikipedia.org/wiki/2011_Christchurch_earthquake - cite_note-Stone-53#cite_note-Stone-53.¹⁷⁵

Failures:

- No major failures identified

Successes:

- Stringent Building Codes
- Hospitals operational despite damage (resiliency)
- Medical care expertly managed (cancelling elective surgery and outpatients, moving existing patients, & prompt infection control)
- Field hospital utilized for suburbs
- System utilizing red/yellow stickers to assess damaged structures
- State of Emergency Level 3 declared
- National coordination
- International best practices followed
- Emergency management structure was in place quickly (within two hours)
- Lead agency designated expeditiously
- Swearing-in of police officers from neighboring countries to keep the peace
- Designated command centers (command was established in the Christchurch Art Gallery, a modern earthquake-proofed building)
- Infrastructure quickly repaired (emergency line was completed in less than three days)
- Volunteer & business organization aid (widespread effort on many private companies and volunteers from all over New Zealand)

E. LOMA PRIETA, CALIFORNIA EARTHQUAKE—OCTOBER 17, 1989

Although occurring nearly 25 years ago, much can be learned from an analysis of the Loma Prieta earthquake. With a large population, multiple modes of transportation and similar methods of emergency response to what exists in New York, a review of the

175 Derek Cheng. “Christchurch Earthquake: Search Teams Leaving no Stone Unturned.” New Zealand Herald (APN Holdings). (February 28, 2011).
[\(Retrieved August 21, 2012\).](http://www.nzherald.co.nz/nz/news/article.cfm?c_id=1&objectid=10709161)

successes and failures of the response following the quake offers insight into problems that may occur in a sprawling urban center such as NYC.

The Loma Prieta earthquake struck the San Francisco Bay Area of California on October 17, 1989, at 5:04 pm and lasted 10–15 seconds.¹⁷⁶ The epicenter of the quake, named after nearby Loma Prieta Peak, was located in an unpopulated area of the Santa Cruz Mountains. Caused by a slip along the San Andreas Fault, the quake measured M 6.9, and killed 63, injured 3,757 and left thousands of people homeless.¹⁷⁷ Approximately 12,000 homes and 2,600 businesses were damaged with many structures not bolted to their foundations left dislodged.¹⁷⁸ Counties as far away as Monterey were affected and unreinforced masonry buildings in Salinas were partially destroyed. Concerned residents slept outside of their homes out of fear of aftershocks. There were 51 aftershocks with magnitudes higher than M 3 in the following 24 hours, and 16 more the second day

http://en.wikipedia.org/wiki/1989_Loma_Prieta_earthquake - cite note-HistoricEarthquakes-32#cite_note-HistoricEarthquakes-32.¹⁷⁹ Deemed the largest earthquake to occur on the San Andreas Fault since the great 1906 San Francisco earthquake, the Loma Prieta earthquake resulted in an estimated \$6 billion

http://en.wikipedia.org/wiki/1989_Loma_Prieta_earthquake - cite note-SanAndreasFault-0#cite_note-SanAndreasFault-0 in property damage, becoming one of the most expensive natural disasters in U.S. history at the time.¹⁸⁰

When the earthquake struck, the third game of the 1989 World Series baseball championship was just beginning. Since both participating teams (the San Francisco Giants and Oakland Athletics) were based in the affected area, many people left work

176 “Earthquake Loma Prieta California 1989.” NIST. http://www.nist.gov/el/disasterstudies/earthquake/earthquake_lomaprieta_1989.cfm. (Retrieved August 28, 2012).

177 Ibid.

178 “Earthquake Hazard and Risk Assessment.” Sonoma County Hazard Mitigation Plan. http://www.sonoma-county.org/prmd/docs/hmp_2011/chapters/ch2.pdf. (Retrieved August 15, 2012).

179 “Historic Earthquakes.” http://earthquake.usgs.gov/earthquakes/states/events/1989_10_18.php/. (Retrieved August 14, 2012).

180 Ibid.

early or stayed late to attend viewings and parties. Luckily, this resulted in unusually light traffic. In fact, initial media reports estimated the death toll to be around 300, failing to realize the World Series' effect on travel; that number was eventually changed to 63 some days after the quake [http://en.wikipedia.org/wiki/1989_Loma_Prieta_earthquake - cite note-12#cite_note-12](http://en.wikipedia.org/wiki/1989_Loma_Prieta_earthquake#cite_note-12#cite_note-12).¹⁸¹

The Loma Prieta earthquake caused severe damage throughout much of the San Francisco Bay Area, damaging structures built on unstable soil in both San Francisco and Oakland. Much of the devastation resulted from liquefaction of soil used to create waterfront land. Other damaging effects included sand volcanoes and landslides. Oakland City Hall was evacuated and extensive property damage occurred in San Francisco's Marina District, 60 miles from the epicenter.¹⁸² This district, built on filled land made of materials containing a high percentage of groundwater, suffered significant liquefaction causing the earthquake's vertical shock waves to ripple the ground more severely [http://en.wikipedia.org/wiki/1989_Loma_Prieta_earthquake - cite note-SFMuseum-7#cite_note-SFMuseum-7](http://en.wikipedia.org/wiki/1989_Loma_Prieta_earthquake#cite_note-SFMuseum-7#cite_note-SFMuseum-7). It was estimated that 57 deaths were directly caused by the earthquake with six fatalities ruled to have been caused indirectly [http://en.wikipedia.org/wiki/1989_Loma_Prieta_earthquake - cite note-ProfMort-1#cite_note-ProfMort-1](http://en.wikipedia.org/wiki/1989_Loma_Prieta_earthquake#cite_note-ProfMort-1#cite_note-ProfMort-1).¹⁸³

Surprisingly, it was not the collapse of homes or businesses that resulted in the most casualties. The largest number of fatalities, 42 in total, were the result of the failure of the Cypress Street Viaduct on Interstate 880 where the top portion of a double-deck freeway collapsed, crushing the cars beneath. This stretch of Interstate 880 was partially built on filled marshland in the 1950s and when the earthquake struck, vibrations were

181 "1989: Earthquake Hits San Francisco." BBC News. (October 17, 1989). http://news.bbc.co.uk/onthisday/hi/dates/stories/october/17/newsid_2491000/2491211.stm. (Retrieved August 29, 2009).

182 "Oakland History Timeline." City of Oakland. <http://www.oaklandnet.com/celebrate/Historytimeline.htm>. (Retrieved August 6, 2012).

183 J.E. Eberhart-Phillips, T.M. Saunders, A.L. Robinson, D.L. Hatch, R.G. Parrish (June 1994). "Profile of mortality from the 1989 Loma Prieta earthquake using coroner and medical examiner reports." <http://www.ncbi.nlm.nih.gov/pubmed/8076160>. (Retrieved August 2, 2012).

amplified and soil liquefaction occurred http://en.wikipedia.org/wiki/1989_Loma_Prieta_earthquake - cite note-HistoricEarthquakes-32#cite note-HistoricEarthquakes-32.¹⁸⁴ A 50-foot section of the San Francisco-Oakland Bay Bridge also collapsed, causing one death and traffic on both decks to come to a standstill. As police rushed to clear traffic, rerouting drivers back the way they had come, miscommunication by emergency workers at Yerba Buena Island caused drivers to be directed the wrong way towards the upper deck of the collapse site.¹⁸⁵ One unfortunate driver actually plunged over the edge and into the collapsed roadbed killing the driver and seriously injuring a passenger.¹⁸⁶ Other notable fatalities included five deaths that resulted from a brick wall collapse on Bluxome Street in San Francisco http://en.wikipedia.org/wiki/1989_Loma_Prieta_earthquake - cite note-SFGate1999-3#cite note-SFGate1999-3.¹⁸⁷ In Santa Cruz, close to the epicenter, half of the six people killed in the quake died on Pacific Avenue and 29 buildings were destroyed along with 206 businesses, practically half of downtown.¹⁸⁸ Streets, sidewalks and the city's century-old water and sewer system below had been ripped apart.¹⁸⁹

Structural collapse was not the only danger, however. At least 27 fires broke out across the San Francisco area, including a major blaze in the Marina District where

184 "Historic Earthquakes." http://earthquake.usgs.gov/earthquakes/states/events/1989_10_18.php/. (Retrieved August 14, 2012).

185 SFGate.com. "Out of the Rubble. Ten Years After: First in a Week-Long Retrospective of the Loma Prieta Quake." Kevin Fagan, Chronicle Staff Writer. (October 12, 1999). <http://www.sfgate.com/bayarea/article/Out-of-the-Rubble-3312129.ph> (Retrieved August 19, 2012).

186 Jack Viets. "They Drove Into Gap: Survivor Recalls Death Of Sister on Bay Bridge." San Francisco Chronicle (October 27, 1989). The Chronicle Publishing Co: A21. <http://lastworldnews-345.blogspot.com/2012/01/san-francisco-earthquake-1989-loma.html>. (Retrieved August 20, 2012).

187 SFGate.com. "Out of the Rubble. Ten Years After: First in a Week-Long Retrospective of the Loma Prieta Quake." Kevin Fagan, Chronicle Staff Writer. (October 12, 1999). <http://www.sfgate.com/bayarea/article/Out-of-the-Rubble-3312129.ph> (Retrieved August 19, 2012).

188 Alan Gathright. "Loma Prieta Earthquake: 15 Years Later / Shaken -- and Then Stirred / Santa Cruz Capitalized on Fate, Working Together to Rebuild Downtown After Quake." SF Gate. (October 16, 2004). <http://www.sfgate.com/bayarea/article/LOMA-PRIETA-EARTHQUAKE-15-years-later-Shaken-2717090.ph> (Retrieved August 5, 2012).

189 Ibid.

apartment buildings sank into a lagoon filled with bay mud.¹⁹⁰ At the intersection of Beach and Divisadero Streets, a natural gas main ruptured causing a major structure fire, and the failure of the hydrant system exacerbated the problem.¹⁹¹ The severely taxed fire department resorted to having bystanders help stretch hose lines long distances as nearby hydrants were inoperable. Eventually, these long stretches paid off, and with local fireboats pumping water to engines on shore, effective extinguishment was accomplished. Parts of San Francisco are now equipped with a level of resiliency in their water supply, however, this system has yet to be tested under actual earthquake conditions.

The rescue effort was swift following the earthquake. Civilians immediately began to attempt to free victims from the rubble of Ford's Department Store and the Santa Cruz Coffee Roasting Company http://en.wikipedia.org/wiki/1989_Loma_Prieta_earthquake - cite note-SFGate2004-14#cite note-SFGate2004-14.¹⁹² Beach lifeguards assisted in search and rescue of damaged buildings in Santa Cruz http://en.wikipedia.org/wiki/1989_Loma_Prieta_earthquake - cite note-SantaCruz271-27#cite note-SantaCruz271-27.¹⁹³ During the quake, Interstate 880 buckled and twisted to its limits before the support columns failed, sending the upper deck crashing to the lower deck below and killing 41 people in their cars. Cars on the upper deck were tossed around violently with some flipping, injuring a number of drivers and passengers. Nearby residents and factory workers quickly initiated rescue using ladders and forklifts http://en.wikipedia.org/wiki/1989_Loma_Prieta_earthquake - cite note-Magnuson5-

¹⁹⁰ "San Francisco Earthquake History 1915–1989." The Virtual Museum of the City of San Francisco." <http://www.sfmuseum.net/alm/quakes3.html#1989>. (Retrieved August 11, 2012).

¹⁹¹ Sherry Elliott. "1989 San Francisco Earthquake." http://sanfrancisco.lovetoknow.com/wiki/1989_San_Francisco_Earthquake. (Retrieved August 27, 2012).

¹⁹² Alan Gathright. "Loma Prieta Earthquake: 15 years Later. Shaken—and Then Stirred. Santa Cruz Capitalized on Fate, Working Together to Rebuild Downtown after Quake." Chronicle. (October 16, 2004). <http://www.sfgate.com/bayarea/article/LOMA-PRIETA-EARTHQUAKE-15-years-later-Shaken-2717090.ph> (Retrieved August 27, 2012).

¹⁹³ Santa Cruz Public Libraries. Local History. "Log of Emergency Response Operations. Tuesday, October 17, 5:04PM, 15-Second Earthquake!" <http://www.santacruzpl.org/history/articles/271/>. (Retrieved August 27, 2012).

[10#cite_note-Magnuson5-10](#) to pull victims out of mangled vehicles.¹⁹⁴ Members of Oakland's Public Works Agency also left a nearby city yard to offer assistance http://en.wikipedia.org/wiki/1989_Loma_Prieta_earthquake - [cite_note-Fowler-36#cite_note-Fowler-36](#). Further away from the collapsed roadway police assisted in searches of affected areas and police dogs were effectively utilized http://en.wikipedia.org/wiki/1989_Loma_Prieta_earthquake - [cite_note-SantaCruz271-27#cite_note-SantaCruz271-27](#). Widespread search operations were organized with teams of dogs and their handlers at work to scour buildings for victims http://en.wikipedia.org/wiki/1989_Loma_Prieta_earthquake - [cite_note-SFMuseum1989-29#cite_note-SFMuseum1989-29](#). Initially helpful, many civilian volunteers soon became a hindrance to professional fire and police rescuers. Those who refused to stop searching were eventually arrested, becoming a sour political issue in the days following http://en.wikipedia.org/wiki/1989_Loma_Prieta_earthquake - [cite_note-SFMuseum1989-29#cite_note-SFMuseum1989-29](#).¹⁹⁵ Private donations poured in to aid relief efforts and a \$3.45 billion earthquake relief package was signed by the president, ultimately funding the recovery operation http://en.wikipedia.org/wiki/1989_Loma_Prieta_earthquake - [cite_note-SFMuseum-7#cite_note-SFMuseum-7](#).¹⁹⁶

Transportation problems were handled particularly well following the disaster. Immediately following the earthquake, San Francisco Bay Area airports closed for damage assessment. Massive cracks in the runway and taxiway of Oakland's major airport, along with damage to the dike used to protect the runway from flooding with bay water, required some restricted operations yet all three major area airports reopened the next morning.¹⁹⁷ Electric power was out to most Santa Cruz customers and many areas

194 "SF 1989 Loma Prieta Quake." http://wn.com/SF_1989_Loma_Prieta_Earthquake#/videos. (Retrieved August 27, 2012).

195 Edward J. Phipps, Edward J. "Overview of Fire Service Responses Near the Epicenter of the Loma Prieta Earthquake," [sfmuseum.org](http://www.sfmuseum.net/1989/report.html) . <http://www.sfmuseum.net/1989/report.html>. (Retrieved August 27, 2012).

196 San Francisco Earthquake History 1915–1989. <http://www.sfmuseum.net/alm/quakes3.html>. (Retrieved August 27, 2012).

197 Ed Magnuson. "Earthquake." Time. P. 7 (October 30, 1989). (Retrieved September 5, 2009).

were left with no water. Limited phone services were operable, however, providing a crucial link to rescue workers. Fortunately the cellular telephone system serving Santa Cruz remained operational throughout and after the earthquake and was an important communications link for the fire department http://en.wikipedia.org/wiki/1989_Loma_Prieta_earthquake - cite note-SFMuseum1989-29#cite_note-SFMuseum1989-29.¹⁹⁸ San Francisco Municipal Railway lost all power when the quake hit, but otherwise suffered little damage and no injuries were reported.¹⁹⁹ Cable cars and electric trains and buses were stalled and diesel buses had to be relied on for limited service until power was restored later that night.²⁰⁰ After 78 hours, 96% of San Francisco's Municipal Railway services were back in operation, including cable cars http://en.wikipedia.org/wiki/1989_Loma_Prieta_earthquake - cite note-Muni-55#cite_note-Muni-55.²⁰¹ The Bay Area Rapid Transit (BART) rail system was virtually undamaged and only closed for safety inspection following the quake. As the quickest way into San Francisco via Oakland for a month due to the damage sustained by bridges, ridership dramatically increased and BART instituted round-the-clock service until December 3, when the system returned to a normal schedule http://en.wikipedia.org/wiki/1989_Loma_Prieta_earthquake - cite note-SFMuseum-7#cite_note-SFMuseum-7.²⁰² Ferry service between San Francisco and Oakland, which ended decades before, was revived during the closure of the Bay Bridge as an alternative form of transportation and a ferry terminal was established as the Army Corps of Engineers dredged a suitable ferry dock at the Berkeley Marina

198 Edward J. Phipps. "Overview of Fire Service Responses Near the Epicenter of the Loma Prieta Earthquake.," sfmuseum.org. <http://www.sfmuseum.net/1989/report.html>. (Retrieved August 27, 2012).

199 William G. Stead, Muni Railway Manager. "Municipal Railway Earthquake Notebook Tuesday, October 17, 1989, 5:04 PM," December 15, 1989 letter to Art Agnos, mayor. <http://www.sfmuseum.net/quake/muni1.html>.

200 Ibid.

201 Ibid.

202 San Francisco Earthquake History 1915–1989. <http://www.sfmuseum.net/alm/quakes3.html>.

http://en.wikipedia.org/wiki/1989_Loma_Prieta_earthquake - cite_note-McDonnell-54#cite_note-McDonnell-54²⁰³

Overall, it could be reasonably stated that the response to the 1989 Loma Prieta earthquake was positive. The death toll was low in comparison to quakes in other populated areas of the world. Numerous challenges were overcome and difficulties were resolved in various creative ways. Rescue efforts were well organized for the most part and normalcy returned to the Bay Area's population quickly, given the circumstances. Emergency managers handled the crisis with efficiency and precision and the actions of the involved agencies should be praised.

Failures:

- Improper handling of traffic (resulting in at least one preventable death)
- Lack of resiliency in San Francisco's water supply for firefighting
- Failure to instruct and control volunteers
- Failure of transportation infrastructure in a known earthquake-prone location

Successes:

- Multiple agencies working well together (FD, PD, lifeguards, public works)
- Creative ways of using bay water for fire extinguishment in some areas
- Organized search efforts
- Public transportation systems expeditiously restored
- Cell phones provided a level of communication resiliency

F. CASE STUDY CONCLUSION

A number of similar themes materialize among these disasters in different parts of the world. For one, building construction, code and regulation play a major role as a passive form of protection. A more dynamic form of protection, however, reveals itself as these case studies show that the more prepared a city is, the better the outcome for its inhabitants. Obviously, due to the current political, economic and cultural climate in NYC some forms of preparedness are more reasonable than others. Emergency managers

203 Janet A. McDonnell, (1993). Office of History, U.S. Army Corps of Engineers. Response to the Loma Prieta Earthquake.

must carefully sift through the lessons learned in these case studies and choose which would better serve the public and which would receive opposition. Building a protective sea-wall in NYC, as exists in many parts of Japan, for example, would not be economically or socially feasible; however, establishing a system to ensure structural engineers assess pre-designated locations following an earthquake deserves serious consideration.

As a result of the previous case studies, emergency managers of NYC have a number of things to consider in planning for a high-risk, low-frequency seismic event which will undoubtedly occur sometime in the future. All of these considerations can be accomplished by high-ranking emergency managers without the need for monetary grants, federal aid or costly training; all of which would be difficult to secure in the current economic climate coupled with the low frequency of NYC's earthquake hazard.

Currently, the FDNY does not have a strategy for responding to an earthquake. Some established response policies are applicable to expected disasters resulting from an earthquake but the wide-spread devastation likely to result from a moderate or severe quake deserves planning and exercise. Some FDNY tactics that can be used under the overall earthquake pre-plan "umbrella" include drafting, collapse operations, high-angle rescue, medical care, hazardous materials mitigation and decontaminations and of course, fire suppression. As the NYC agency with the fastest response time, it is crucial that the FDNY establish an overall strategy to manage an earthquake response. Current response strategies are in place for dealing with hurricanes, radioactive threats, riots, vessels in distress and even aviation accidents; this begs the questions: why not earthquakes?

The 2003 NYCEM study suggests that approximately 900 fires would result in the Tristate area following a M 6, putting fire departments under severe strain. Compare that to Hurricane Sandy in October, 2012, which resulted in a total of 21 serious fires, destroying more than 200 homes and businesses across NYC.²⁰⁴ One of these fires destroyed more than a hundred homes in Breezy Point, Queens. Another 73 structural

²⁰⁴ Arun Kristian Das. "FDNY: Most Storm-Related Fires Were Electrical." MyfoxNY.com. (January 21, 2013). <http://www.myfoxny.com/story/20419608/fdny-most-storm-related-fires-were-electrical>.

fires were deemed to be storm-related. In total, 68 fires were electrical, 20 were caused by an open flame, such as a candle or stove top, and 6 were sparked by generators.²⁰⁵ Prior to the storm, FDNY Commissioner Salvatore Cassano deployed an additional 500 members and more than two dozen rigs to the most vulnerable areas along the city's coast.²⁰⁶ With so many emergency calls during the hurricane, the number of available units, which usually hovers around 90%, plummeted to a mere 9% at the storm's peak.²⁰⁷ There is no doubt that FDNY resources were seriously strained during this hurricane, even though reserve units were placed in service to deal with the surge in calls.

Current Citywide Incident Management (CIMS) Policies for natural disasters have a number of agencies designated as "primary agencies" (command agencies) under the broad term of "natural disasters."²⁰⁸ Natural disasters need to be broken down into different incident types and specific agencies designated in command for each separate disaster. This is important as incident command roles may change depending on emergencies caused by a particular disaster. In the case of an earthquake, anticipated extensive structural collapse and fire involvement would require greater involvement and command by the FDNY, whereas the NYPD, in charge of water and ice rescue, would have a lesser role in command and implementation of earthquake response. It is recommended that under "Earthquakes," the primary agency designation be modified to include agencies such as the Department of Buildings (DOB) and Department of Environmental Protection (DEP), while other agencies, such as Department of Information Technology and Telecommunications (DOITT), Verizon, and various transit agencies should be added to "subject matter experts." Table 6 portrays the current CIMS protocol.

²⁰⁵ Ibid.

²⁰⁶ Joe Kem "FDNY Commissioner Salvatore Cassano on Hurricane Sandy Response." (November 11, 2012). <http://www.nydailynews.com/new-york/fdny-chief-takes-news-sandy-response-article-1.1200088>.

²⁰⁷ Ibid.

²⁰⁸ New York City Fire Department. "FDNY Manual All Unit Circular 276." (March 1997).

Table 6. NYC CIMS Primary Agencies and Subject Matter Experts. (From: FDNY Manuals, AUC 276).

INCIDENT TYPE	PRIMARY AGENCIES	POTENTIAL PRIMARY AGENCIES SUBJECT MATTER EXPERT
Aviation Incident	FDNY, NYPD	NTSB, PANYNJ, USCG
CBRN/Haz-Mat (no <i>suspected terrorism or crime</i>)	FDNY, NYPD	DEP, DOHMH, USGC
Public Health Emergency	DOHMH, FDNY, NYPD	HHC, GNYHA
Explosion	FDNY, NYPD	DDC, DOB, HPD
Natural Disaster/Weather	DOT, DSNY, FDNY, NYPD, OEM	DDC, DEP, DOB, DOHMH, Con Ed, Keyspan, LIPA
Rail Incident	FDNY, NYPD	Amtrack, MTA, NJT, PANYNJ
Electrical	FDNY, NYPD	Con Ed, Keyspan, LIPA
Gas	FDNY, NYPD	Con Ed, Keyspan, LIPA
Steam	FDNY, NYPD	Con Ed
Water	DEP, FDNY, NYPD	Con Ed, Keyspan, LIPA
Telecommunication	DOITT, FDNY, NYPD	Verizon

The FDNY also lacks the current positive working relationships with private businesses, volunteer organizations and even the military, as was the case in the successful case studies. As earthquakes are low frequency events in NYC, there are no current pre-planned areas for command or mustering of FDNY members. Additionally, current tactics do not take into account the limited number of available resources that can be expected following an earthquake. The large number of units dedicated to a single civilian trapped in a trench cave-in, as per present FDNY SOP's, will not be available for a single incident following the multiple fires and emergencies resulting from a powerful quake.

Emergency supplies on hand must also receive consideration following a seismic event. To meet anticipated needs during a category 3 or 4 hurricane, OEM has developed a comprehensive Coastal Storm Plan that includes detailed procedures for evacuating and sheltering residents. The City's shelter system consists of 65 evacuation centers and up to 509 hurricane shelters, including eight special medical needs shelters.²⁰⁹ To supply and staff the shelter system, OEM maintains an emergency stockpile of essential supplies and a database of nearly 25,000 City employees who would be called upon to manage evacuation centers and emergency shelters.²¹⁰ The FDNY also has a plan identified as "BIOPOD," which calls for the assembly of multiple points-of-distribution of vaccines and medicines for members, which can also be implemented following a large earthquake.²¹¹ The stability of these shelters and availability and adequacy of supplies and medicine following an earthquake must be examined to ensure they would meet the needs of evacuees and victims following a large-scale earthquake.

Levels of resiliency, such as use of helicopters to access obstructed areas and setting up field hospitals to care for the injured, are not currently part of the FDNY's operational procedure. Additionally, there is no priority for locations of fire suppression should the FDNY's resources become overwhelmed and no strategy to account for the difficulty of utilizing existing recall procedures in the face of widespread devastation and interrupted modes of transportation. Finally, the FDNY needs to discuss the legal consequences of certain decisions and attain the rights to implement emergency procedures in the face of impending disaster. By reviewing these case studies, the FDNY can avoid mistakes made by foreign response agencies.

The successful strategies implemented by New Zealand during the Christchurch earthquake of 2011 underscore the importance of an effective pre-plan. The other case studies portray failures in the emergency response even though these countries are

²⁰⁹ "NYC Office of Emergency Management (OEM) Conducts Hurricane Drill," OEM. (June 2, 2008). http://www.nyc.gov/html/oem/html/news/08_02_06_hurrex2008.shtml.

²¹⁰ Ibid.

²¹¹ New York City Fire Department. "FDNY Manual Fire Tactics and Procedures, Emergency Response Procedures Addendum 1 Chapter 2." (August 2004).

located in high-impact seismic zones. The leaders of the FDNY must first recognize the seismic threat to NYC and then formulate a strategy to deal with this threat. In order to start the FDNY on the road to success, a number of recommendations are made that will emulate the successes of these case studies while avoiding failures. By focusing on the positive aspects of responses to previous earthquakes, the FDNY can modify these successful strategies and tailor them to the vast and complex City of New York.

Recommendations

NYC Pre-plan Considerations / Lessons to be learned:

1. Plan for quick, efficient aid from local, military and international experts.
2. Explore the possibility of setting up a temporary field hospital.
3. Explore the possibility of utilizing open waterways for medical ocean vessels, military ships and boats distributing large amounts of resources. Also consider the feasibility of commandeering existing commercial vessels for emergency transportation and use.
4. Explore the possibility of using local helicopters for survey and to bypass damaged roads.
5. Pre-plan open, wide areas, with unimpeded access routes for mustering of emergency responders.
6. Plan for extensive, city-wide resource management such as distributed food and water.
7. Review procedures for declaring a “state of emergency” early, when the need is evident.
8. Evaluate special hazards city-wide (chemical plants, areas with extensive excavation work, Indian Point.)
9. Analyze the potential of using local, undamaged medical clinics for emergency treatment as well as trained medical professionals.
10. Establish rapport with private companies (including infrastructure and utility companies) to ensure emergency resource allocation, transportation and infrastructure repair can be quickly accomplished.
11. Maintain points-of-contact with infrastructure supervisors to ensure the timely isolation of gas, power, electric and water when necessary. Ensure resilient means of communicating with these individuals.
12. Establish a method whereby structural engineers can ensure a quick survey of designated access points (bridges, roads, tunnels,) for use by emergency responders.

13. Identify procedures to assess the integrity of damaged buildings and the use of easily-identifiable methods (numbers, letters, colors,) to assign hazard levels post-disaster.
14. Follow international best practices for earthquake response.
15. Pre-plan for a designated Lead Agency.
16. Identify and pre-determine possible command centers (strong, resilient structures.)
17. Identify areas and buildings with back-up generators.
18. Pre-plan additional dependable water sources for fire suppression.
19. Contact Volunteer & Business organizations (and possibly include them in tabletop exercises.)
20. Evaluate the feasibility of establishing curfews.
21. Discuss law enforcement options for force protection and review existing procedures.
22. Brainstorm the possibility of increasing penalties for crimes during “states of emergency.”
23. Plan to stockpile anticipated emergency supplies and medicine specific for an earthquake response.
24. Plan for the possibility of a tsunami and its associated hazards should one strike NYC coastal areas concurrent with, or subsequent to, a large earthquake.

IV. ANALYSIS OF VULNERABILITIES

In this section, the city's vulnerabilities are exposed with each borough of NYC given a priority hazard assessment score based on the author's professional opinion using known facts and other data to estimate preferential allocation of the FDNY's limited resources following a major earthquake. In most cases each borough will be given a score of 1 through 5, with 1 being the lowest hazard score for the particular vulnerability, and 5 being the highest. In cases where only one or two boroughs can be identified as having a particular vulnerability, that borough/s will receive a higher score while all others will share the same lower score. The same will be done in any case where a particular borough has a significant advantage over others in regard to a particular vulnerability; that borough will have the lowest priority hazard score with others sharing the higher mark. These scores are based on a combination of available data and a professional analysis by a NYC fire officer (the author.)



Figure 6. Boroughs of NYC. (From: Date: July 12, 2009. User: PerryPlanet. File: New York City District Map.svg. http://wikitravel.org/shared/File:New_York_City_District_Map.png).

NYC is mainly a city of islands. Because of this, damage caused by an earthquake has the potential to isolate these islands, along with first responders. It is crucial for FDNY Borough Commanders to ensure strategies are formulated with this in mind. The immediate aftermath of an earthquake is likely to be the most crucial period in regards to saving lives and mitigating emergencies. Each borough must initially operate with the limited resources on hand until the true extent of the city-wide crisis becomes realized. After the initial immediate response, available resources will need to be allocated to areas of need. It is the intent of this section to identify areas of need based on available data

and professional experience so that a proper pre-plan can be developed. It must be stressed here, however, that resource allocation among the five boroughs may be delayed due to the structural vulnerability of bridges, roads and tunnels between these boroughs. Procedures must be put in place that will ensure the safety of emergency responders in traversing these access points following a seismic event. One option is to have established Department of Buildings (DOB) rapid assessment teams automatically dispatched to pre-designated bridges, roads and tunnels ensuring they are safe prior to FDNY use. The feasibility of ensuring DOB timely response, however, must be explored. At the very least, policies can be implemented ordering FDNY units to standby at the entrance of these critical points until a knowledgeable chief officer arrives on scene and assesses their potential for collapse. As emergency response progresses, it is anticipated that resources may be allocated and hazardous areas prioritized as real-time critical information becomes available allowing agency leaders to make sound decisions regarding mitigation. With these plans in place and proper strategies implemented, it is envisioned that control of the entire city would gradually be regained using a continually evolving Incident Action Plan (IAP) based on a thorough analysis of the disaster.

Survival for as long as fourteen days has been documented in earthquakes around the world. However, the survival rate percentage has its greatest decline just one day after the occurrence.²¹² Even with the chaos of on-going fire and emergency activity, within 24 hours FDNY members should have an estimate of which collapsed structures in their area could have potential survivors. These areas must be immediately made known to the Fire Department Operations Command (FDOC) and areas throughout the city prioritized. With priorities established, buildings deemed most hazardous can be searched by Urban Search and Rescue (USAR), followed by specially trained FDNY Special Operations Command (SOC) units and finally, Operations-Level trained Engine and Ladder

²¹² New York City Fire Department. “FDNY Manual Fire Tactics and Procedures, Collapse.” (June 2007).

Companies searching buildings presenting the least hazard to personnel.²¹³ In any case, a long-term goal would be to have every damaged structure searched, at the latest, within fourteen days following the earthquake. As emergency managers increase control of the situation in the days following the quake and damaged buildings are both identified and prioritized, by using NYC agencies, volunteers, and even national and global aid, fourteen days is a realistic goal following a large earthquake.

Table 7. Time of Extrication vs. Survival Rate. (From: FFP Collapse 11.7.1).

Time of Extrication	Survival Rate
30 minutes	99.3%
1 day	81%
2 days	36.7%
3 days	33.7%
4 days	19%
5 days	7.4%

A. POPULATION

The population of NYC is widespread and varied. A 2011 census revealed NYC's landmass to be over 47,000 square miles, entailing approximately 411 people per square mile.²¹⁴ Measured against the national average of just over 87 people per square mile,

213 There are 28 FEMA USAR task forces nationwide, including one in NYC. Each consists of 72 personnel, mostly Technical Rescue trained Fire Department members, with additional skilled personnel such as physicians and structural engineers. USAR teams can be readily mobilized within 6 hours of notification and self sufficient for 72 hours. Their use should be utilized and the FDOC should ensure OEM is immediately contacted for task force dispatch. New York City Fire Department. "FDNY Manual Fire Tactics and Procedures, Collapse." Section 10.3 (June 2007).

214 "State & County QuickFacts." United States Census Bureau.
<http://quickfacts.census.gov/qfd/states/36000.html>.

one can see that NYC is heavily populated.²¹⁵ 13.7% of the population is 65 years of age or older and 22% are under 18 years of age (with 6% being under 5 years).²¹⁶ Additionally, 21.7% are foreign-born, living and working in NYC.²¹⁷ The number of people living or working within the five boroughs of NYC is truly a challenge to first responders in the event of a black swan. Evacuations, victim-tracking and incident command are likely to be confusing and overwhelming. Current emergency management methods will have to be expanded and improvised in order to account for missing and trapped victims, as well as ensure a “risk versus reward” approach is taken under dangerous conditions. Figure 7 reveals a breakdown of NYC’s population by borough:

Change in Population, Census Bureau Estimates April 2010 to July 2011				
	2010 <u>Census</u>	2011 <u>Census Bureau Estimates</u>	Change: Census 2010 and Estimates 2011 <u>Number</u>	Percent <u>Percent</u>
New York State	19,378,102	19,465,197	87,095	0.45
New York City	8,175,133	8,244,910	69,777	0.85
Bronx	1,385,108	1,392,002	6,894	0.50
Brooklyn	2,504,700	2,532,645	27,945	1.12
Manhattan	1,585,873	1,601,948	16,075	1.01
Queens	2,230,722	2,247,848	17,126	0.77
Staten Island	468,730	470,467	1,737	0.37
NYC as % of NYS	42.19	42.36	80.12	

Source: 2010 Census; Census Bureau Current Estimates Program

Figure 7. NYC’s Population by Borough 2010–2012. (From: <http://www.nyc.gov/html/dcp/html/census/popcur.shtml>).²¹⁸

²¹⁵ “State & County QuickFacts.” United States Census Bureau. <http://quickfacts.census.gov/qfd/states/36000.html>.

²¹⁶ Ibid.

²¹⁷ Ibid.

²¹⁸ It should be noted here that this hazard assessment is based purely on population, which could be related to casualties. However, it is the combination of a number of complex factors, including population, infrastructure and time of day, which will determine the hazard.

Based on population number, a potential hazard assessment has been assigned as follows:

- Manhattan: Potential Hazard Score 3
- Bronx: Potential Hazard Score 2
- Brooklyn: Potential Hazard Score 5
- Queens: Potential Hazard Score 4
- Staten Island: Potential Hazard Score 1

B. SUBWAY SYSTEM

Handling over 4.5 million passengers daily, NYC's subway system is among the busiest urban transit systems in the world and with 6,200 cars servicing 25 lines, it is arguably one of the most complex.²¹⁹ The subway system services NYC's boroughs 24 hours a day, 7 days a week, making civilians susceptible at any time an earthquake may strike. The potential for complex rescues must also be considered with two-thirds of the 660 mile working track system located underground, and the remainder elevated or at grade level.²²⁰ The potential for casualties is great in NYC's complex transportation system. Underground portions of the subway may collapse while other portions flood. Train derailments are likely and passengers may be trapped in unfamiliar, dark and smoky confined spaces without power. The absence of power is certainly preferable in some instances as self-evacuating passengers face a greater degree of danger if unknowingly stepping near an energized third rail. Lack of service underground will surely delay emergency calls for assistance from deep tunnels. Portions of elevated train tracks may also collapse, raining debris onto vehicles and pedestrians on the streets below. Each borough has its own unique challenges relating to NYC's subway system.²²¹

- Manhattan: 2011 estimated annual ridership of 904,762,522. 118 stations. Hosts the lowest station at 180 ft below street level at 191st.²²² Also hosts

²¹⁹ K. Ascher. "Anatomy of a City." Penguin Books USA 2007, 26.

²²⁰ Ibid.

²²¹ "Annual Subway Ridership." MTA.info.
http://www.mta.info/nyct/facts/ridership/ridership_sub_annual.htm.

²²² "Annual Subway Ridership." MTA.info.
http://www.mta.info/nyct/facts/ridership/ridership_sub_annual.htm.

the busiest, and arguably most complex, station in the subway system at 42nd St and 8th Ave in Times Square.²²³ As of 2011, out of the top ten busiest subway stations in NYC, nine are located in Manhattan.²²⁴ Potential Hazard Score: 5

- Bronx: 2011 estimated annual ridership of 142,957,026. 68 stations. Potential Hazard Score: 2
- Brooklyn: 2011 estimated annual ridership of 352,296,972. 157 stations. Hosts the highest station at Smith / 9th Street. Potential Hazard Score: 4
- Queens: 2011 estimated annual ridership of 240,626,516. 78 stations. Potential Hazard Score: 3
- Staten Island: 2008 estimated annual ridership of 5,593,828. 22 stations. Hosts only grade-level tracks, most likely requiring less complex rescues post-quake.²²⁵ Potential Hazard Score: 1

Even an earthquake of small magnitude causing little to no damage throughout the subway system would require an overwhelming response of FDNY resources. As one of NYC's largest consumers of electricity, each year the transit system consumes some 1.8 billion kilowatt hours of power.²²⁶ A loss of this power could result in widespread panic and resultant need for orderly evacuation and medical care. Perhaps most importantly, power should remain off if impatient or fearful victims unwilling to wait for overwhelmed FDNY responders decide to self-evacuate. Evacuating along catwalks or at track level exposes unwary civilians to third rails and catenary wires, both extremely dangerous should power abruptly be restored. It is crucial that contact be maintained with the appropriate Desk Superintendent at the Transit Control Center, utilizing existing Department procedures, to ensure power is not abruptly restored. In the event Department radio traffic prevents proper notification to ensure power remains off, members should use "blue light" telephones or transit workers (supervisors, operators and conductors) to relay the current situation and need for power to remain off. A separate system of power provides station lighting, tunnel lighting, signals and ventilation equipment in the tunnel

223 Ibid.

224 "Subways," MTA.info. <http://www.mta.info/nyct/facts/ffsubway.htm>.

225 "System Map," MTA.info. <http://www.mta.info/nyct/maps/simap.htm..>

226 Ibid.

and consideration should be given to loss of this power as well, further inducing panic among those self-evacuating under dangerous conditions.

Due to increased training, safety equipment, and system-wide resilience, the potential for train collisions would not be greatly increased during an earthquake however, derailment and structural collapse is still a very strong possibility. Additionally, the problem of flooding remains a danger. Each day pumps remove up to 13 million gallons of rain and other water from the subway system.²²⁷ This water is ultimately dispersed into NYC's storm-water system but debris blocking drains along the tracks coupled with an overwhelming volume of water could lead to disastrous flooding in many tunnels. Under-river tubes present their own problems as the tubes themselves may leak creating a flooding condition compounded by the electric hazard of the 3rd rail and overhead power lines.

In the event of an earthquake, serious consideration should be given to having NYC Transit Authority (NYCTA) personnel direct the majority of victims of stopped or lightly damaged trains to safety with FDNY operations reserved for major derailments, collapse and transport of non-ambulatory victims. The use of diesel-powered trains on intact transit lines to move personnel and equipment until power is restored should also be explored, although failure of natural and mechanical ventilation within tunnels can result in diesel fumes becoming detrimental to both responders and evacuees. In any case, NYCTA has 62 diesel-electric locomotives capable of pulling non-powered flat cars and crane cars and the benefits of their use should be explored.²²⁸ The FDNY and NYCTA require a closer relationship in planning for natural disasters and direct lines of communication and pre-planning will be necessary to ensure the safety of all transit customers.

227 "System Map," MTA.info. <http://www.mta.info/nyct/maps/simap.htm>.

228 Ibid.

C. UTILITIES

1. Electric

NYC's power grid is one of the largest systems of electricity delivery in the world with daily consumption of approximately 11,000 megawatts during summer months, slightly more than in the entire country of Chile.²²⁹ This is due, in part, to the city's heavy reliance on urban necessities such as the subway system, traffic signals and elevators. High-voltage power is delivered from a number of different generating plants and is stepped down by some 33,000 transformers and distributed through the world's largest underground electric cable system.²³⁰ Access to over 80,000 miles of underground electric cable is provided by 250,000 manholes throughout the city.²³¹ NYC itself is responsible for roughly one-tenth of all electric power used within the city.²³² It is important to note here that most of the city's power is generated from within the five boroughs, with four generating plants in Queens alone accounting for roughly half of the energy output in the city.²³³ Central generating plants are assisted by smaller generators to meet peak demands and electricity generated within the city is supplemented with power created outside of the five boroughs. The Indian Point Nuclear Power Plant produces up to 20% of the city's demand with additional generating stations located in New Jersey, Connecticut, Pennsylvania and upstate NY.²³⁴

An earthquake with an epicenter far from NYC may have consequences for NYC's power distribution, however, a quake in or around NYC is likely to be much

²²⁹ Solar One, "Electricity in NYC." (2008).
<http://communityresourcecesscied.wikispaces.com/file/view/Electricity+in+New+York+City+Lesson+Plan.pdf>.

²³⁰ K. Ascher, "Anatomy of a City." New York, NY: Penguin Books USA, 2007, 92.

²³¹ Ibid.

²³² Ibid., 95.

²³³ The remainder are spread across Brooklyn, the Bronx, and Staten Island. Ascher, K. "Anatomy of a City." New York, NY: Penguin Books USA, 2007, 99.

²³⁴ Because of design constraints related to NYC's distribution grid, limits are placed on how much power may be provided from generating plants outside the five boroughs. The city must be capable of providing 80% of anticipated power needed with the remaining 20% being delivered from outside the city. Ascher, K. "Anatomy of a City." New York, NY: Penguin Books USA, 2007, 98.

worse, affecting the majority of power distribution. Even with reliance on generating plants far from the city, transmission and distribution lines may be damaged or disrupted following a powerful earthquake, negating any potential resiliency from outside the city regardless of how much power is increased. The serious potential for power disruption will increase with the magnitude of the earthquake; however, even less-powerful quakes have the potential of causing significant damage. Although Con Edison plays a major role in the electricity transmission business, in 1999 the corporation sold many of its electric generating plants to NRG Energy, Keyspan, and U.S. Power Generating Company; a fact to consider when attempting to build positive relationships as part of the planning for numerous utility emergencies likely after a quake.²³⁵

Although NYC's power grid has often been considered to be one of the most reliable in the world, the simplicity in which it can fail has been proven three times:²³⁶

- 1965 Blackout: Caused by a transmission line failure in Ontario.
- 1977 Blackout: A thunderstorm took down power lines north of the city.²³⁷
- 2003 Blackout: Power failures as far away as Ohio triggered shutdowns affecting much of the eastern seaboard.

In all of these scenarios, it took hours to restore power to parts of the system. It can be anticipated that a moderate to severe earthquake in NYC may result in weeks for even a partial restoration of power.

Following a moderate or severe earthquake, the utility distribution network located in underground manholes, prevalent in Manhattan and present in other boroughs, will most likely become inoperable and may result in widespread fire damage extending into buildings as well as generating toxic fumes within structures, most notably carbon monoxide, a deadly, insidious gas that is undetectable without special instrumentation.

235 K. Ascher, "Anatomy of a City." New York, NY: Penguin Books USA, 2007, 98.

236 Ibid., 108.

237 The 1977 blackout in New York City led to the first federal law concerning electricity reliability. It allowed the government to propose voluntary standards, an authority never before exercised. Unfortunately, as evidenced by the 2003 blackout, the possibility of system failure continues to exist. Clayton, M. "Progress on Preventing Blackouts." The Christian Science Monitor. (June 18, 2007). <http://www.csmonitor.com/2007/0618/p02s01-ussc.html>.

Repair of NYC's underground electric distribution network will be timely. High-voltage cables, should they need repair, can take up to 12 hours to splice together.²³⁸

Overhead power lines found in all boroughs of NYC except Manhattan could be toppled, cutting power to residents, starting fires and electrocuting unlucky or unwary civilians. Additionally, these toppled poles and wires, even when confirmed de-energized and grounded, are likely to cause widespread hindrance of roads and thus, even capable emergency responders. Underground service may not cause immediate hindrance to first responders but will be significantly harder to repair over the long term. With all factors taken into consideration, priority hazard scores are given to each borough based on the immediacy of the threat posed by electrical emergencies. As widespread power outages are to be expected, the most significant threat aside from electrocution would be fire, explosion and carbon monoxide/other deadly gas generation. This threat is significantly greater and much more difficult to mitigate when underground and so, higher scores are given to boroughs with total or significant electric service located underground.

- Manhattan: All electrical service located underground. 21,216 miles of underground cable and 60,026 manholes and service boxes. Potential Hazard Score: 5
- Bronx: Electrical service above ground and below ground. 10,901 miles of underground cable, 29,668 manholes and service boxes and 2,679 miles of overhead wire on 18,023 utility poles. Potential Hazard Score: 2
- Brooklyn: Electrical service above ground and below ground. 27,317 miles of underground cable, 76,697 manholes and 3,552 miles of overhead wire on 26,288 utility poles. Potential Hazard Score: 4
- Queens: Electrical service above ground and below ground. 24,795 miles of underground cable, 80,921 manholes and service boxes and 6,995 miles of overhead wire on 39,670 utility poles. Potential Hazard Score: 3
- Staten Island: Electrical service above ground and below ground. 2,748 miles of underground cable, 5,654 manholes and service boxes and 5,019 miles of overhead wire on 29,422 utility poles. Potential Hazard Score: 1²³⁹

²³⁸ K. Ascher, "Anatomy of a City." New York, NY: Penguin Books USA, 2007, 106.

²³⁹ "Electric System." Con Edison. http://www.coned.com/newsroom/energysystems_electric.asp.

One important power source that should be taken into consideration for emergency use following an earthquake is NYC's fleet of power barges located primarily in Gowanus Bay and at Sunset Park along the Brooklyn waterfront.²⁴⁰ Usually used to supplement power during peak demand, these power barges can serve as an emergency or temporary power source (barring any potential water damage following an earthquake). The Gowanus site, with 32 combustion units, is the world's largest floating power plant.²⁴¹ Emergency generators located throughout a number of NYC firehouses can also serve to provide electricity for a short period of time, powering tools and communication devices as long as these units, and the adjoining firehouse, are not damaged during or after the quake.

2. Steam

NYC's subterranean steam network is the biggest steam system in the world. Generated from seven plants across the city, steam flows up to 75 mph through over 100 miles of mains and service pipes, located under 1,200 manholes.²⁴² There are five steam generating plants located in Manhattan, with one in Brooklyn, and one in Queens.²⁴³ Steam mains may be anywhere from four to 15 feet below ground and steam pipes can be several feet in diameter (the most common being between two and three feet).²⁴⁴ Mostly made of steel, older cast-iron pipes are still used for steam distribution and are vulnerable to cracking. Often coated with asbestos, these steam pipes can result in a haz-mat situation at the most inopportune time. Maintained by Con Edison, steam demand peaks during the coldest months of the year. Approximately 100,000 homes and businesses,

²⁴⁰ K. Ascher, "Anatomy of a City." New York, NY: Penguin Books USA, 2007, 98.

²⁴¹ Ibid.

²⁴² Ibid., 116.

²⁴³ Three of these plants are co-generation plants, producing steam as a by-product of electricity generation. K. Ascher. "Anatomy of a City." New York, NY: Penguin Books USA, 2007, 119.

²⁴⁴ There are exceptions. The steam main running along Park Ave under the Metro-North Rail tunnel is approximately 30 feet deep. Ascher, K. "Anatomy of a City." New York, NY: Penguin Books USA, 2007, 119.

including the Empire State Building, rely on NYC's steam system. Additionally, local area hospitals make regular use of steam, mostly for sterilization.²⁴⁵

In NYC, the two most concentrated areas of steam distribution, and consequently where some of NYC's buildings are tallest, are in lower Manhattan and midtown Manhattan. In July 2007, a 24" steam pipe located underground in Manhattan exploded causing widespread damage, panic, injuries and one death.²⁴⁶ An earthquake could cause a number of these incidents, spreading already limited FDNY resources thin and releasing asbestos into the air contaminating civilians and responders.

- Manhattan: Greatest concentration of steam distribution. Steam generating plants. Potential Hazard Score: 3
- Bronx: No steam distribution. Potential Hazard Score: 1
- Brooklyn: Steam generating plant. Potential Hazard Score: 2
- Queens: Steam generating plant. Potential Hazard Score: 2
- Staten Island: No steam distribution. Potential Hazard Score: 1

3. Water

This subject is particularly important aside from disruption of available drinking water and damaged caused by flooding and leaking pipes. The disruption of water supply to NYC presents extreme challenges to the FDNY following an event where resultant structural fires are almost a certainty. Without a steady, reliable water supply, fires may go unchecked, consuming and destroying much of NYC. And so, restoration of this utility may very well be as important, or even more important, than electricity. The NYC water system relies on 18 collecting water reservoirs, some as far as 125 miles north of the city, as well as two storage reservoirs and four distributing reservoirs.²⁴⁷ Three aqueducts are used to move water from the upstate reservoirs to NYC citizens. Constructed at different times and having different shapes, NYC residents depend on

245 K. Ascher, "Anatomy of a City." New York, NY: Penguin Books USA, 2007, 117.

246 Mark Lukasiewicz, "Steam Explosion Jolts Manhattan, Killing 1." NBCnews.com. (July 18, 2007). http://www.msnbc.msn.com/id/19837147/ns/us_news-life/t/steam-explosion-jolts-manhattan-killing/.

247 These storage and distributing reservoirs are within the city's boundaries. Ascher, K. "Anatomy of a City." New York, NY: Penguin Books USA, 2007, 154–155.

each for an uninterrupted flow of water. Perhaps the most well known is the New Croton Aqueduct, constructed between 1885 and 1890, running from the Croton Reservoir System to Jerome Park Reservoir, located in the Bronx.²⁴⁸ With substantial cracks already throughout the various aqueducts, resulting in a loss of an estimated 36 million gallons of water each day, a moderate earthquake can be the catalyst that effectively stops the flow of fresh water into the city's millions of residents.²⁴⁹

Two large water tunnels distribute water throughout the five boroughs, with a third currently under construction, designated to be completed by 2020.²⁵⁰ Water Tunnel No. 1, completed in 1917, stretches 18 miles from the Bronx into Manhattan, and ultimately into Brooklyn.²⁵¹ Covered by at least 150 ft of rock in most places, the tunnel is 200 to 300 feet deep and carries 500 to 600 million gallons of water each day.²⁵² One can clearly see that repairs to this tunnel, should extensive damage occur, will be no easy task. Water Tunnel No. 2 was active in 1936 and runs from the Bronx into Queens, and ultimately connects to the five mile long Richmond tunnel, supplying water to Staten Island.²⁵³ Distribution of water to city residents is almost entirely dependent on gravity. About 3% to 5% of city water requires additional pressure to reach end users with pumping stations located in Washington Heights in north Manhattan, Douglaston in eastern Queens, and Grimes/Todt Hill on Staten Island.²⁵⁴ Power loss to one or all of these pumping stations can cause a loss of pressure in certain areas of the city. With an intricate mix of underground service lines, distribution mains, regulators and approximately 118,000 fire hydrants throughout the city, there is potential for serious water loss due to ground shaking caused by an earthquake.

248 The other two aqueducts are the Catskill Aqueduct and Delaware Aqueduct. Ascher, K. "Anatomy of a City." New York, NY: Penguin Books USA, 2007, 156.

249 K. Ascher, "Anatomy of a City." New York, NY: Penguin Books USA, 2007, 162.

250 Ibid., 158

251 Ibid.

252 Ibid.

253 Ibid.

254 K. Ascher, "Anatomy of a City." New York, NY: Penguin Books USA, 2007, 159.

About half of NYC's water distribution system was built before 1930 and consists of unlined, cast-iron pipes, with the remaining half subsequently built stronger to reduce susceptibility to corrosion and failure.²⁵⁵ The municipal water system as a whole is designed to ensure hydrant pressures of 45 to 60 psi and anything less can seriously hamper firefighting.²⁵⁶ For water shortage (drought) emergencies, the city does have the ability to draw from river water as well as neighboring water systems. Additionally, certain supply lines are interconnected with lines serving central New Jersey and Philadelphia.²⁵⁷

It is important to point out the dangers associated with water storage systems throughout the five boroughs when affected by an earthquake. With an estimated 10,000 to 15,000 water towers (most often conical shaped, rooftop wooden tanks) throughout NYC, the potential for a few of these to collapse onto the roof, or off of the roof in some cases, must not be overlooked.²⁵⁸ Additionally, even in the best-case scenario where water supply and pressure is not affected by a seismic event, attention must be given to the possibility of water treatment plants being compromised. DEP samples NYC's water through compliance sites and surveillance sites as well as monitors supplementary groundwater systems serving the city. A strong relationship between the FDNY and DEP must ensure open lines of communication to protect the health of NYC's citizens and first responders should these systems be compromised.²⁵⁹

- Manhattan: Potential Hazard Score: 2
- Bronx: Potential Hazard Score: 2
- Brooklyn: Potential Hazard Score: 2
- Queens: Potential Hazard Score: 2

255 K. Ascher, "Anatomy of a City." New York, NY: Penguin Books USA, 2007, 162.

256 Ibid., 160.

257 Ibid., 161.

258 Ibid., 166.

259 Compliance sites consist of three stations (where sample is taken, upstream, and downstream) and surveillance sites which are located on water trunk mains. Both serve as early warning systems for water quality problems. Areas with supplementary groundwater sources include Laurelton, Queens Village, and Cambria Heights. Ascher, K. "Anatomy of a City." New York, NY: Penguin Books USA, 2007, 169.

- Staten Island: The Silver Lake storage tanks (two 50-million-gallon tanks) locate 20ft below ground, ensures a two-day supply of water is kept on hand.²⁶⁰ Potential Hazard Score: 1

4. Sewer

With over 6,600 miles of sewer pipes, approximately 100 pumping stations, and 14 wastewater treatment plants, NYC processes an astonishing 1.3 billion gallons of sewage every day.²⁶¹ These pipes range from 6 inches to more than 89 inches in diameter and are generally buried more than 10 feet underground, below the level of clean water pipes.²⁶² Installed at various points in NYC's history and constructed from a number of different materials, these pipes may fail during an earthquake and depending on the magnitude and amount of ground movement, even gravity may not prevent the mixing of raw sewage with clean drinking water. The city's complex sewer system is not the only problem as some homes among the outer boroughs still rely on septic tanks. Although these tanks may be damaged during an earthquake, the fact that they are isolated systems lessens the chances of the greater NYC water supply becoming contaminated, and so, greater attention can be paid to the widespread NYC sewage system.

When wastewater treatment plants are unable to handle a large amount of sewage (a common occurrence during heavy rainfall) excess flow is diverted into a combined sewer overflow outfall and discharged into the harbor untreated.²⁶³ Should an earthquake damage or disrupt NYC's wastewater treatment system, the potential for large amounts of sewage dumping out into the harbor and contaminating NYC's waterways is great and may have far-reaching effects. The 2003 Northeast blackout alone resulted in over 400 million gallons of raw sewage being dumped into NYC's waterways.²⁶⁴ This must be considered following a quake where water mains are disrupted and FDNY Engine Companies must resort to drafting from natural waterways for adequate water supply

260 K. Ascher, "Anatomy of a City." New York, NY: Penguin Books USA, 2007, 161.

261 Ibid., 170, 178.

262 Ibid., 172.

263 K. Ascher, "Anatomy of a City." New York, NY: Penguin Books USA, 2007, 174.

264 Ibid., 182.

when fighting fires. The hazard priority assessment below takes into account the number and capacity of their sewage treatment areas and plants in each of NYC's boroughs.²⁶⁵

- Manhattan: Two treatment centers totaling 420 million gallons a day. Potential Hazard Score: 4
- Brooklyn: Five treatment centers totaling 675 million gallons a day. Potential Hazard Score: 5
- Bronx: One treatment center totaling 200 million gallons a day. Potential Hazard Score: 2
- Queens: Four treatment centers totaling 375 million gallons a day. Potential Hazard Score: 3
- Staten Island: Two treatment centers totaling 100 million gallons a day. Potential Hazard Score: 1

5. Gas

Con Edison serves Manhattan, the Bronx and north Queens, while Keyspan supplies gas to Brooklyn, Staten Island, and south Queens. Fortunately, with the exception of very limited amounts of liquefied natural gas held at power plants in the city, natural gas is not stored in the city.²⁶⁶ As gas is distributed by a large network of underground piping, the potential for extreme gas emergencies exists following an earthquake. Although plastic and steel pipes are used to replace damaged piping today, previously used cast iron pipes, brittle and aged, are still prevalent. With shut-off valves and bypass valves throughout the system, gas mains are generally at least three feet underground and fully susceptible to ground movement. Structural and underground gas leaks are a common response for FDNY units under normal, ideal conditions. In fact, the number of serious natural gas pipeline incidents in New York City shot up dramatically in 2011, increasing by 400 % compared to the previous year.²⁶⁷

²⁶⁵ Priority is based on the number of capacity of sewage treated in each borough, not the number of facilities. Although it can be assumed that the more facilities a borough has the more resilient the system. Ascher, K. "Anatomy of a City." New York, NY: Penguin Books USA, 2007, 178.

²⁶⁶ K. Ascher, "Anatomy of a City." New York, NY: Penguin Books USA, 2007, 113.

²⁶⁷ "Natural Gas Pipeline Incidents in NY Soared in 2011, Led By Alarming Increase in NYC Pipeline Failures." Naturalgaswatch.org. (February 16, 2012). <http://www.naturalgaswatch.org/?p=121>.

Damaged underground piping will result from a moderate quake causing regulators and relief valves to fail, and permitting explosive amounts of natural gas to buildup both underground and in buildings. Gas lines will rupture in the street, as well as within structures, starting numerous fires that may become uncontrollable due to emergency responder limitations following this disaster. FDNY private sector points-of-contact (Con Ed and National Grid) must be able to be reached following an earthquake to ensure timely control and isolation of gas mains. Established procedures for electrical emergencies whereby FDNY Battalion Chiefs are able contact Con Ed Control Center or Substation Shift Managers directly via Department-issued cell phones should be expanded to include Con Ed Gas and National Grid Gas Services.²⁶⁸ Additionally, secondary and tertiary means of communication should be established in the event cell phone service is disrupted. Established Department Radio channels, Handie-talkies, land-lines, or 800 MHz radios are all viable options, and their expected resiliency during a seismic event should be explored. As all natural gas distributed within the five boroughs is provided by Con Edison or National Grid, and presents the same hazards, the potential hazard scores are as follows:

- Manhattan: Potential Hazard Score: 3
- Bronx: Potential Hazard Score: 3
- Brooklyn: Potential Hazard Score: 3
- Queens: Potential Hazard Score: 3
- Staten Island: Potential Hazard Score: 3

6. Pipelines

Pipelines in and around NYC carrying gasoline, aviation fuel and natural gas may also rupture, overwhelming first responders. Pipeline provider Buckeye Partners MLP operates two 12" diameter steel pipes, one carrying gasoline and the other carrying kerosene-based aviation fuel, that traverse underground portions of Brooklyn, Queens and Staten Island.²⁶⁹ The pipeline operates at 1,200 psig at Linden, New Jersey with

²⁶⁸ New York City Fire Department. "FDNY Manual All Unit Circular 340," (June 2008).

²⁶⁹ Ibid., 2.

maximum service pressure on terminal piping and delivery lines up to 200 psig.²⁷⁰ The Iroquois pipeline is located throughout portions of the Bronx and carries natural gas through a 24" diameter high pressure steel pipe.²⁷¹ This pipeline is operated by Con Edison and has a maximum allowable operating pressure of 1,440 psig, though it will typically operate between 400 and 1,100 psig.²⁷² All of these pipelines have safety valves and metering stations. More importantly, the FDNY has detailed procedures and semi-annual drills on how to handle an emergency in one of the sections of these pipelines. Unfortunately, following an earthquake a number of pipeline sections may fail resulting in numerous conflagrations or at the very least, hazardous material leaks.

With FDNY resources already spread thin, standard operating procedures for handling these emergencies will have to be amended to allow expeditious control. Improving the relationship between the FDNY and pipeline providers while exploring capabilities of a system-wide shut-down, or at the very least, extensive isolation, should be considered.

- Manhattan: No pipelines traverse Manhattan. Potential Hazard Score: 1
- Bronx: Iroquois Pipeline. Potential Hazard Score: 2
- Brooklyn: Buckeye Pipeline. Potential Hazard Score: 2
- Queens: Buckeye Pipeline. Potential Hazard Score: 2
- Staten Island: Buckeye Pipeline. Potential Hazard Score: 2

D. BRIDGES/TUNNELS

There are 14 major bridge and tunnel crossings connecting the various parts of NYC to each other and to neighboring jurisdictions.²⁷³ Living and working in one of the most populated cultural, financial and political centers in the world, the citizens and emergency responders of NYC rely on key components of the city's transportation infrastructure for day-to-day activities. One critical component of this infrastructure is the

²⁷⁰ New York City Fire Department. "FDNY Manual All Unit Circular 149." (June 2008). 2.

²⁷¹ Ibid., 1.

²⁷² Ibid.

²⁷³ K. Ascher, "Anatomy of a City." New York, NY: Penguin Books USA, 2007, 45.

vast network of bridges and tunnels that connect NYC's boroughs. Each borough faces its own challenges and problems in the event ground transportation becomes limited. Taking into account building configuration, population density, traffic conditions and potential isolation from adjacent jurisdictions and cities, the borough of Manhattan is by far the most vulnerable.

Four major vehicular tunnels connect Manhattan as well as six major bridges. Some are under the Department of Transportation's (DOT) jurisdiction while others are operated by different agencies like the Port Authority, NYC Department of Parks & Recreation and Amtrak.²⁷⁴ In assessing the principles of risk, competitive exclusion, self-organized criticality, tragedy of the commons and the paradox of enrichment, it can be determined that the primary threat for this level of infrastructure is natural hazards; most notably, an earthquake.

A 2003 study in the Journal of Performance of Constructed Facilities examined over 500 bridge collapses in the U. S. and found that the average age of the failed structure was 52.5 years.²⁷⁵ As of 2008, NYC had three bridges rated "poor" after their last inspections, meaning components of the bridges needed rehabilitation, not that they were unsafe.²⁷⁶ A single bridge or tunnel labeled unsafe and prohibited from use, even for emergency personnel, is not likely to seriously affect the FDNY's operational capacity; however, multiple avenues of ground transportation likely to be damaged following an earthquake may severely limit logistics, resource management and operations within the FDNY. A moderate or severe earthquake simultaneously destroying portions of the city's bridges and tunnels is the biggest threat facing NYC. Indeed, a powerful earthquake may collapse sections of both bridges and tunnels, negating their use as well as causing widespread flooding. Due to the lack of frequency of earthquakes in the NYC area, the city's transportation infrastructure is particularly vulnerable to this

²⁷⁴ NYC.gov. http://www.nyc.gov/html/dot/html/faqs/faqs_bridge.shtml.

²⁷⁵ NYtimes.com.
http://topics.nytimes.com/topics/reference/timestopics/subjects/b/bridges_and_tunnels/bridge_disasters/index.html.

²⁷⁶ NYC.gov. http://www.nyc.gov/html/dot/downloads/pdf/bridgerpt08_1.pdf.

threat. The simultaneous destruction of a great majority of NYC's bridges and tunnels, or at the very least a period of time negating their use, can pose extreme problems for the FDNY.

Each bridge has its own unique design, from suspension bridges to trestle bridges, to steel arch bridges. Many are movable bridges including retractile bridges, vertical lift bridges and bascule bridges (drawbridges). Some bridges are very complex, such as the Williamsburg Bridge with eight traffic lanes, two transit tracks and a pedestrian walkway. Tunnels likewise vary in design and length. Materials surrounding the tunnel consist of cast-iron, concrete, or varying composite materials. The number of traffic lanes, as well as emergency exits and ventilation towers, differ throughout these complex modes of transportation. NYC's tunnels all traverse bodies of water and consist of varying designs of air supply and exhaust systems that must be taken into account should portions of a tunnel collapse during seismic activity. Additionally, various degrees of water flooding and leakage should be taken into account as well as the potential for installed pumps to be overwhelmed. Each bridge and tunnel requires its own analysis and response plan in the event of a disastrous earthquake.

In the event a large-magnitude quake occurs, it will be crucial for the FDNY to have a system to replace its exhausted members, transport equipment and ensure the availability of much-needed resources to the "islands" of NYC which will likely be inundated with emergency and fire calls related to the natural disaster itself. In the initial stages of the disaster, FDNY members recalled can be ordered to firehouses closest to their residence and make use of available equipment to begin operations. The downside to this is the unbalanced distribution of the majority of "blue-collar" firefighters responding in the outer boroughs, closer to home, leaving Manhattan with the fewest number of members able to report for duty by vehicle or on foot. As FDNY leadership collaborates and formulates an IAP, a more balanced distribution of resources can be allocated based on where the need is greatest. The vast network of waterways in and around NYC can be the FDNY's greatest asset. The use of fireboats as well as commandeering other vessels (ferries, water taxis, sightseeing vessels) to transport

members and equipment would be invaluable as part of a well-developed strategic operating plan. The possibility of transporting fire apparatus by vehicle-carrying ferryboats should be considered, with the various ports of NYC serving as staging areas for the FDNY.

A large disaster cutting off all ground transportation into and out of the various boroughs of NYC does not have to result in a logistical nightmare leaving the FDNY without capabilities. By thinking “outside the box” and using available resources, the FDNY can ensure an effective response to even the most unlikely black swan. In the initial stages, when the stability of bridges and tunnels are suspect, Manhattan and Staten Island emergency response will be limited to the resources contained within these respected boroughs. Utilization of fire boats and commandeering other vessels for transportation of personnel is an option during the initial stages. After a structural engineer is able to confirm the safety of bridges and/or tunnels, units and personnel can be routed via these points to where they are needed. It is also recommended that procedures be established to ensure the automatic dispatch of a rapid-assessment team from DOB to pre-designated bridges, roads and tunnels identified as particularly vulnerable to a seismic event. Establishing a pre-plan with DOB officials identifying the importance of each access point and prioritizing the order of inspection of these bridges and tunnels post-disaster is necessary to ensure quick and effective emergency response. Also essential is the use of NYPD personnel to keep bridges and tunnels clear of all traffic with the exception of emergency and other permitted vehicles during the initial stages following a quake. The priority hazard assessment below takes into account each borough’s reliance on NYC’s bridge and tunnel network including individual bridge and tunnel vulnerability.²⁷⁷

- Manhattan: The oldest crossing, Highbridge, connects Manhattan to the Bronx over the Harlem River. The Queensboro Bridge is the busiest East River crossing. The Brooklyn Bridge is the oldest and busiest of the lower Manhattan bridge crossings into Brooklyn. The Holland Tunnel is the oldest vehicular tunnel in the region. The Lincoln tunnel consists of three

²⁷⁷ K. Ascher, “Anatomy of a City.” New York, NY: Penguin Books USA, 2007, 127.

tubes with lanes varying direction depending on the time of day (i.e., rush hour). Potential Hazard Score: 5

- Bronx: The elevated tracks near Yankee Stadium are part of the longest railroad-owned bridge. The George Washington Bridge's 14 lanes make it one of the world's busiest suspension bridges.²⁷⁸ Potential Hazard Score: 3
- Brooklyn: The longest municipally owned bridge is the Gowanus. The Brooklyn Battery Tunnel is the longest continuous underwater vehicular tunnel in the world. Potential Hazard Score: 4
- Queens: The Queens Midtown Tunnel permits traffic to and from Manhattan and accommodates thousands of vehicles a day. Potential Hazard Score: 2
- Staten Island: The Bayonne Bridge is one of the longest steel arch bridges in the world with a mid-span clearance of 151 ft.²⁷⁹ Potential Hazard Score: 4

E. BUILDINGS

As of July, 2012, NYC is home to the second highest number of skyscrapers (over 500), more than any other city in the world except Hong Kong.²⁸⁰ It is also home to five of the top twenty tallest buildings in North America. Following an earthquake, the emergencies faced by first responders are varied and in large, complex buildings may include dealing with panic, mass evacuations, hazardous materials situations, stalled elevators, suspended scaffolds and loose or fallen debris. To compound the problem, older buildings without emergency power, or where emergency power has failed, will complicate rescues as firefighters may have to climb over 50 flights of stairs to extinguish a fire or remove occupants from a single trapped elevator.

²⁷⁸ In 2003, the George Washington Bridge was subject to a seismic retrofit. The Port Authority of New York and New Jersey. (August 5, 2010). http://www.panynj.gov/corporate-information/pdf/board_minutes_aug_5_2010.pdf.

²⁷⁹ This list does not include World Trade Center 1, currently under construction. "North America's Tallest Buildings – Top 20." Emporis.com. <http://www.emporis.com/statistics/tallest-buildings-northamerica>.

²⁸⁰ Emporis.com. <http://www.emporis.com/statistics/most-skyscrapers>.

Much of the island of Manhattan sits on a deep layer of soft, post-Ice Age sediment over extremely hard rock, “a juxtaposition of geological extremes.”²⁸¹ Further analysis of NYC’s geology and soil composition, particularly areas where liquefaction is likely to occur, is certainly warranted. Regrettably, various earthquake-mitigating requirements applied to NYC building codes were absent until the mid-1990s, however, a basic analysis reveals that generally, well-designed towers in the city’s skyline would most likely survive an M 6 quake. Unfortunately, unreinforced masonry townhouses, where most residents live, might not.²⁸² As shown in Figure 8, 79% of buildings in Manhattan alone are constructed of unreinforced masonry, a true hazard for victims and rescuers in the event of an earthquake.²⁸³

²⁸¹ TLC.com “Cities at Risk for Earthquakes: New York City.” http://tlc.discovery.com/convergence/quakes/articles/citiesatrisk_04.html.

²⁸² Ibid.

²⁸³ Unreinforced masonry constitutes 79% of all buildings in Manhattan. This type of construction is brittle and does not absorb motion as well as other structure types do (wood, steel, and reinforced concrete). The New York City Area Consortium for Earthquake Loss Mitigation. http://www.dhses.ny.gov/oem/mitigation/archive/documents/S3.I.vi_Earthquake_Hazard_Profile.pdf.

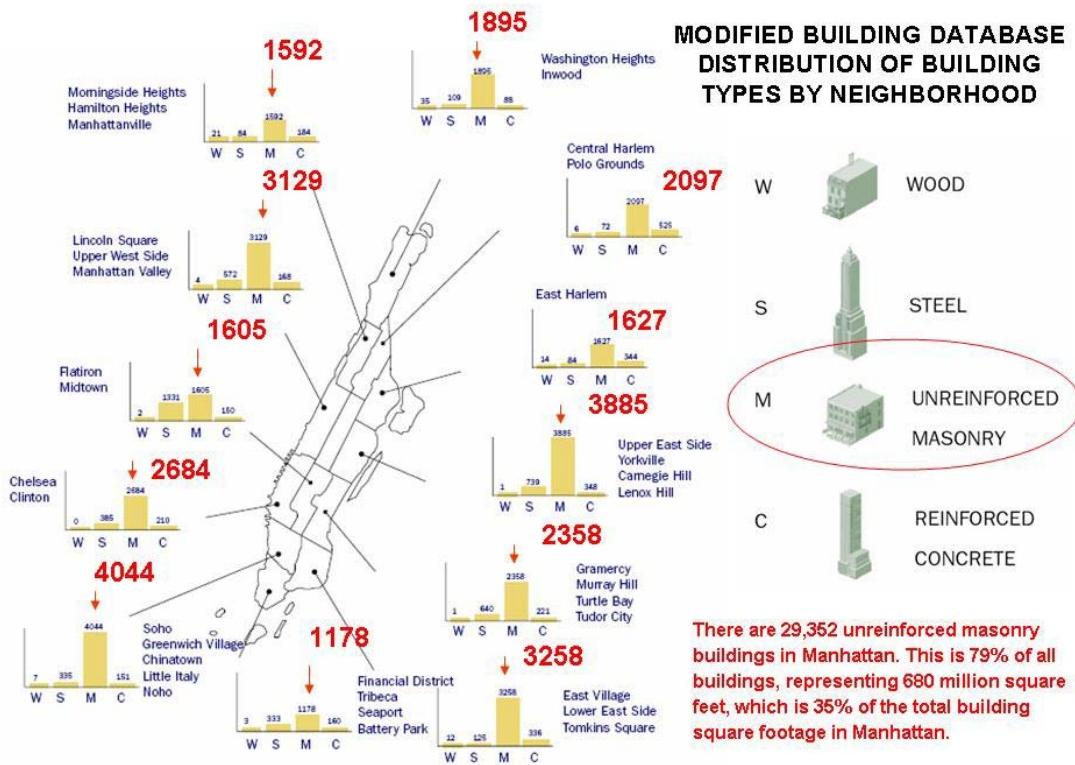


Figure 8. Building Types of NYC by Neighborhood. (From:
http://www.dhses.ny.gov/oem/mitigation/archive/documents/S3.I.vi_Earthquake_Hazard_Profile.pdf).

The worst-case-scenario in the event of an earthquake would be a total collapse of major portions of high-rises, requiring extensive search efforts, specialized units and numerous resources. Adequate victim-tracking will be mandatory and thorough searches necessary. Large buildings would require timely searches and sidewalks may have to be closed off to the civilian population if loose or unrestrained objects are a concern. Although the exact number of high-rise structures per borough is not able to be obtained, Manhattan invariably has the greatest number of skyscrapers with Staten Island having the least. Potential hazard scores are assigned with this in mind, also accounting for the total number of buildings in each borough.²⁸⁴

²⁸⁴ Emporis.com, <http://www.emporis.com/statistics/most-skyscrapers>.

- Manhattan: 41,500 buildings. Majority of high-rises in NYC (over 75 ft high). Potential Hazard Score: 5
- Bronx: 80,888 buildings. A few high-rises (over 75 ft high). Potential Hazard Score: 3
- Brooklyn: 271,052 buildings. A number of high-rises (over 75 ft high). Potential Hazard Score: 4
- Queens: 224,528 buildings. A number of high-rises (over 75 ft high). Potential Hazard Score: 4
- Staten Island: 108,975 buildings. Very few high-rises (over 75 ft high). Potential Hazard Score: 1

F. COMMUNICATIONS

Resiliency in communications is essential for any first responder and with equipment reserves, back-up generators and a number of tested ways to effectively communicate in various circumstances, the FDNY is one of the most prepared organizations in the world. The residents of NYC, however, may not be. Surprisingly, an estimated 20% of the city's citizens do not have regular phone service in their homes.²⁸⁵ Yet, residents dial 911 an average of 23 times each minute, close to 12 million times each year.²⁸⁶ Police, fire and EMS rely heavily on NYC's communications system for response and incident command. Modern communication systems are complex, consisting of many components including copper wire, coaxial cable, fiber optic cable, carrier hotels, and switching stations, to name a few.

There are approximately 80 switching stations spread out across the five boroughs with each containing a complex array of computer-controlled digital and fiber optic equipment as well as supplementary power, cooling and ventilation systems.²⁸⁷ Some of this equipment is so sensitive that many of these switching stations are windowless; the absence of glass panes protect telephone switches and sensitive electronic equipment from dust, temperature and humidity.²⁸⁸

²⁸⁵ K. Ascher, "Anatomy of a City." New York, NY: Penguin Books USA, 2007, 132.

²⁸⁶ Ibid., 134

²⁸⁷ Ibid., 127.

²⁸⁸ Ibid.

Having the largest cellular market in America, there are approximately 10.5 million cell-phone subscribers in NYC.²⁸⁹ The system is frequently subject to overload, with calls commonly dropped during peak hours. In 2002, an estimated 120,000 calls to 911 did not go through due to cell-phone failure.²⁹⁰ Many high-rise buildings of NYC frequently obstruct cell signals under normal conditions. Following an earthquake where parapet walls crumble and roofs collapse, it can be expected that a number of cell phone towers will be inoperable and a system-wide shutdown of cell phone communications anticipated. According to NYC's Department of Information Technology and Telecommunications (DOITT) the mobile telecommunications franchise allows cell phone providers to install and use telecommunications equipment and facilities, including telecommunications boxes and antennae, on public street-light poles, traffic-light poles and utility poles to provide mobile telecommunications services in all five boroughs.²⁹¹ The resiliency of the structures on which crucial telecommunications equipment is installed during an earthquake is questionable. As the telecommunications network is generally reflective of the number of users, the loss of communications are liable to affect all boroughs equally. Likewise, the fact that equipment generally does not pose a significant threat to the general public, the following potential hazard scores are provided equally to each borough as shown below.

- Manhattan: Potential Hazard Score: 1
- Bronx: Potential Hazard Score: 1
- Brooklyn: Potential Hazard Score: 1
- Queens: Potential Hazard Score: 1
- Staten Island: Potential Hazard Score: 1

G. SPECIAL PROJECTS

At any given time there are a number of complex projects underway throughout the five boroughs of NYC. Special consideration must be given to these sites as they will

289 K. Ascher, "Anatomy of a City." New York, NY: Penguin Books USA, 2007, 124.

290 Ibid., 127.

291 "Asked Questions: Mobile Telecommunications Franchises Frequently." NYC Information Technology and Telecommunications. <http://www.nyc.gov/html/doitt/html/faq/telecommunications.shtml>.

each present their own unique hazards, vulnerabilities and personnel accountability. Presently, there are two major construction projects within NYC. The first is the construction of NYC Water Tunnel No. 3, the largest capital construction project in NYC's history.²⁹² With an estimated total length of 60 miles, construction began in 1970 and will not be complete until 2020, at a cost of nearly \$6 billion dollars.²⁹³ The tunnel traverses and connects all five boroughs and runs from 800 feet below ground at its deepest, to approximately 400 feet below ground at its shallowest.²⁹⁴ For the purposes of NYC's earthquake analysis, it is important to note that the Manhattan section of the tunnel is currently being worked on and scheduled to be activated in 2013.²⁹⁵

Previously excavated using "drill and blast" techniques, the 10 to 24 foot diameter tunnel is presently being hollowed out through use of Tunnel Boring Machines.²⁹⁶ It is anticipated all future construction of the water tunnel will utilize this technology and FDNY first responders will have to familiarize themselves with complicated rescues that may result from even a weak earthquake. It must be expected that unstable work areas around the tunnel and Tunnel Boring Machines will present challenges regarding shoring, rescue and victim transport from locations hundreds of feet down from the surface of NYC streets.

The second project is the construction of the 2nd avenue subway line. A number of methods are being used to construct this tunnel underneath the densely-populated east side of Manhattan, including utilization of a Tunnel Boring Machine. Other portions will be excavated using the "cut and cover" method and mining coupled with "drill and blast."

292 "City Water Tunnel No. 3," New York City Department of Environmental Protection. (February 2006), <http://www.nyc.gov/html/dep/pdf/factsheet.pdf>.

293 Ibid.

294 Ibid.

295 "DEP Completes Key Milestone for City Water Tunnel No. 3," NYC.gov (May 8, 2010). http://www.nyc.gov/html/dep/html/press_releases/10-45pr.shtml.

296 "City Water Tunnel No. 3," New York City Department of Environmental Protection (February 2006), <http://www.nyc.gov/html/dep/pdf/factsheet.pdf>.

²⁹⁷ Just like Water Tunnel 3, complex rescue and recovery operations can be expected should seismic activity trap or injure workers in or around portions of the tunnel. The most recent proposed construction schedule has the 2nd avenue subway open for passenger service in 2016.²⁹⁸

As both of these extensive projects are currently underway in Manhattan, potential hazard scores are distributed as indicated below.

- Manhattan: Potential Hazard Score: 3
- Bronx: Potential Hazard Score: 1
- Brooklyn: Potential Hazard Score: 1
- Queens: Potential Hazard Score: 1
- Staten Island: Potential Hazard Score: 1

The data clearly shows that NYC is a complex habitat with a large number of vulnerabilities that can result in the loss of time, money and lives in the event of a moderate or severe seismic event. By exposing these vulnerabilities and educating emergency managers as to the potential hazards first responders may face in the aftermath of an earthquake, steps can be taken to prepare NYC response agencies to operate safely and efficiently in even the most shocking disaster scenario.

H. FDNY RESOURCE ALLOCATION

Finally, based on existing data and a professional assessment of the potential hazard scores for each of NYC's vulnerabilities, resource allocation for each borough can be estimated prior to a major earthquake. Figure 9 indicates which boroughs will require more staffing, equipment, resources and expertise following a devastating earthquake due to an analysis of NYC's major vulnerabilities.

The data shows Manhattan to be the most vulnerable and the area where the largest number of FDNY resources will be required. Manhattan is followed by Brooklyn,

²⁹⁷ "Second Avenue Subway," MTA (August 2002), <http://www.mta.info/capconstr/sas/documents/2ndave.pdf>.

²⁹⁸ Kim Tingley. "Tunneling Below Second Avenue," The New York Times. <http://www.nytimes.com/2012/08/05/magazine/tunneling-below-second-avenue.html?pagewanted=all>.

Queens, the Bronx and Staten Island, in that order, for risk assessment and resource allocation. This is only an estimate with all known factors taken into consideration. As always, resource allocation may change on the day of the disaster as potential threats are revealed and other mitigating circumstances are made known; however, Figure 9 should be a starting point when pre-planning for this black swan.

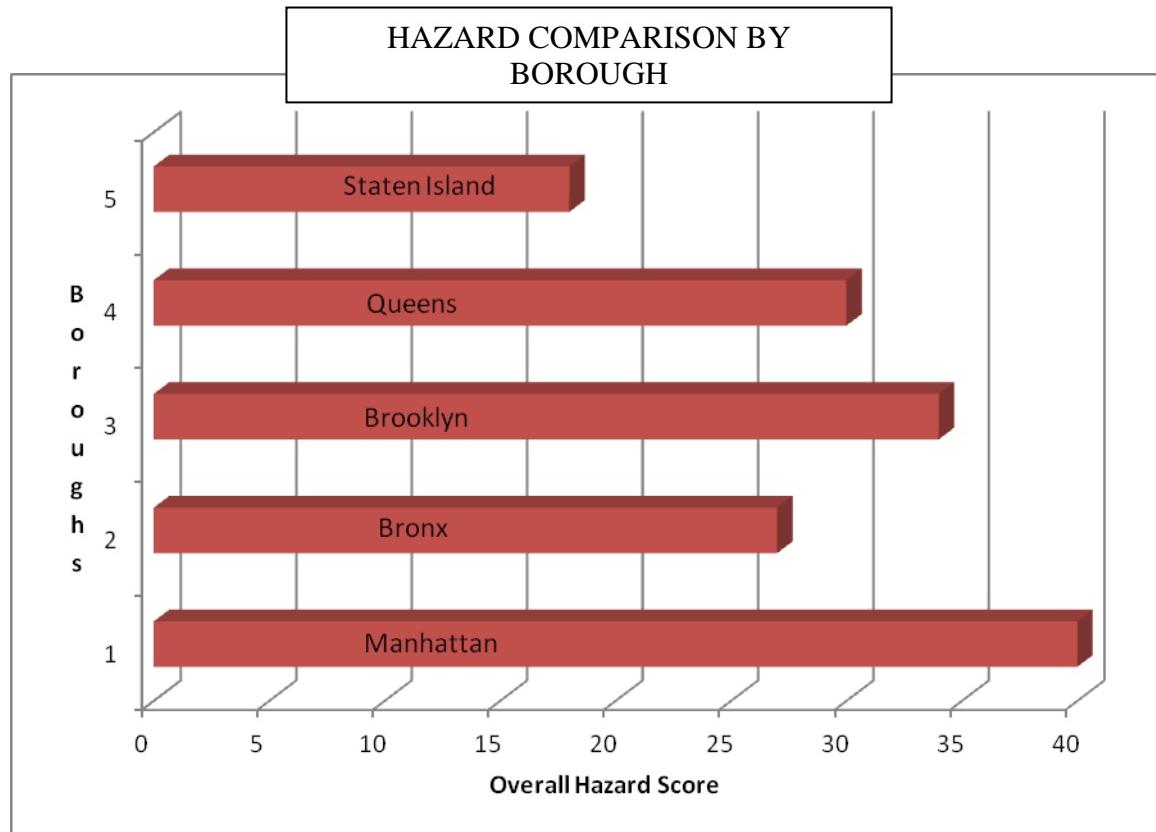


Figure 9. Final Hazard Comparison by Borough

V. RESPONSE OF THE FDNY AND PRE-PLAN CONSIDERATIONS

In addition to NYC's vulnerabilities, there are a number of factors the FDNY must consider following the occurrence of a major earthquake. Depending on the extent and severity of the quake, these factors may be major considerations requiring the full focus and effort of the FDNY or may require little to no attention at all. Regardless, these factors must be considered when formulating a pre-plan for an earthquake in or around NYC.

A. FIRES

One of the most dangerous outcomes following an earthquake is the loss of lives and property due to widespread conflagrations. History has shown that uninhibited fires can be responsible for wiping out whole districts in vulnerable cities. Aside from the destruction caused by tremors during the famous 1906 San Francisco earthquake, it was the associated fire that resulted in 80% of the total damage.²⁹⁹ In fact, the two largest peace-time urban conflagrations in history were the fires associated with the 1906 San Francisco earthquake and the fires following the 1923 Tokyo earthquake, the latter which resulted in the great majority of the estimated 140,000 fatalities.³⁰⁰

Obviously the fire service has come a long way since the early 1900's in regards to fire science, technology and equipment, but the danger still exists, and may be greater than ever with the presence of numerous petroleum-based products and furnishings, large pipelines carrying flammable gases and liquids, and the reduction of firefighting staffing throughout the country.³⁰¹ NYC is especially prone to its firefighters becoming overwhelmed because of these issues. In fact, 35 fire companies were cut between 1972

299 Charles R. Scawthorne, "The Shakeout Scenario," USGS. (March 3, 2008), <http://www.colorado.edu/hazards/shakeout/fire.pdf>.

300 Ibid.

301 Michael R. Waters, "How Economy Is Challenging Fire Protection Services," Insurance Journal. (January 25, 2010), <http://www.isomitigation.com/docs/fire-peril.pdf>.

and 1975 and the 1975 reduction in firefighter staffing levels reduced engines from five firefighters per company to four and ladder companies from six firefighters to five.³⁰² In 2003, six more fire companies were closed and in 2011, all engines were reduced to four firefighters.³⁰³ All of this occurred in a city where, from 1993 to 2011, structural fires remained fairly constant while non-fire and medical emergencies significantly increased; and the city's population continues to grow. As the FDNY operates at the busiest levels throughout its history, the challenges firefighters will face following an earthquake will have to be met with aggressiveness, determination and quick-thinking.

In NYC, numerous sources of ignition coupled with obstructed response paths are only the beginning of the fire problem following a quake. With water mains damaged throughout the city, firefighters will have to rely on other sources of water such as booster tanks, water towers in unaffected structures and drafting. Booster tanks will be adequate for extinguishing incipient fires and allowing a quick search and rescue of some affected structures, however, a more reliable, constant source of water is needed. Large, complex structures as well as high-rise buildings equipped with wet standpipe/sprinkler systems and water towers may be a source of supply depending on the integrity of these systems post-quake. Identifying and utilizing draft sites will be invaluable in FDNY efforts to mitigate the numerous expected fires. Intact pools, lakes, ponds, bay and river water are all potential positive sources and long stretches of hose lines must be expected. Due to the location and nature of these sources, it is recommended that sites without close, natural bodies of water be identified and alternate methods of water delivery explored.

Due to widespread collapse of large buildings and infrastructure, fire apparatus may not be able to access blocked roads. Possible solutions must be weighed against their level of difficulty to carry out. FDNY apparatus are very large vehicles capable of moving debris if necessary. Additionally, the FDNY operates a number of smaller

³⁰² Kat Sonia Thomson, "Fire Department Performance Management: Is Public Policy on the Map?" Fire Engineering (August 1, 2012), <http://www.fireengineering.com/articles/print/volume-165/issue-8/features/fire-department-performance-management-is-public-policy-on-the-map.html>.

³⁰³ Ibid.

vehicles such as Brush Fire Units (BFU), Gator Units, and Rapid Response Vehicles (RRV), which can traverse a large variety of territory under a multitude of conditions. Forthwith activation of these vehicles, some of which are equipped with winches, water supply, and a variety of useful equipment, should be considered in FDNY's planning. The use of helicopters to reach especially isolated areas should also be explored. Calling for, and using, the National Guard's flat-bed trucks to traverse flooded areas for firefighting is also a possibility, as successfully proven during the 1997 Grand Forks, North Dakota flood.³⁰⁴ As a measure of resiliency, and a method to "cut NYC's losses," one final recommendation is to prioritize structures involved in, or exposed to, fire in order to adequately suppress conflagrations with the limited number of resources available following a catastrophic earthquake.

The brave members of the FDNY will have many challenges to overcome following a moderate or severe earthquake in NYC and it will only be through effective leadership, critical thinking and bravery that the numerous fires expected will be able to be suppressed and the lives and property of the citizens of NYC ultimately saved.

304 State Historical Society of North Dakota,
[http://digitalhorizonsonline.org/cdm4/results.php?CISOOP1=exact&CISOFIELD1=CISOSEARCHALL&CISOROOT=/uw-ndshs&CISOBOX1=Grand+Forks+\(N.D\)..+Fire+Dept](http://digitalhorizonsonline.org/cdm4/results.php?CISOOP1=exact&CISOFIELD1=CISOSEARCHALL&CISOROOT=/uw-ndshs&CISOBOX1=Grand+Forks+(N.D)..+Fire+Dept).

FDNY Structural Fire, Medical and non-Fire Emergency Responses 1993-2011

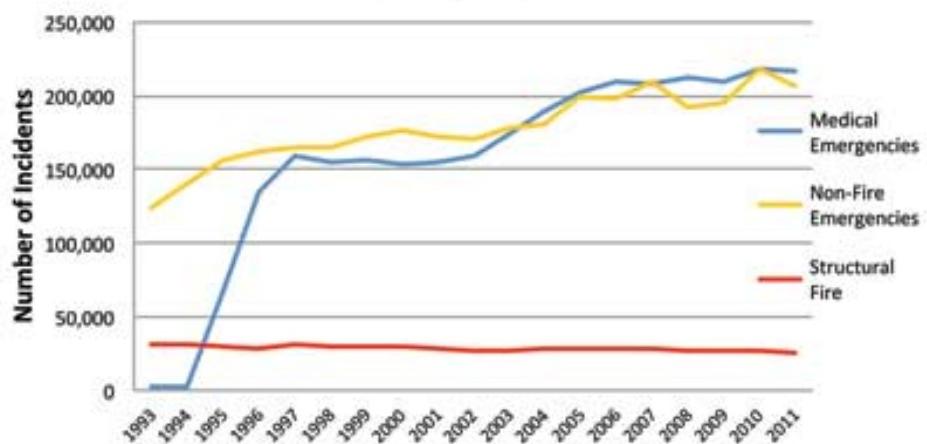


Figure 10. FDNY Responses 1993–2011. (From: <http://www.fireengineering.com/articles/print/volume-165/issue-8/features/fire-department-performance-management-is-public-policy-on-the-map.html>).

B. INTERAGENCY OPERATIONS

The Citywide Incident Management System protocol observed by NYC first responders is likely to be overridden in the initial stages of the rescue effort. Timely command, coordination and effective leadership will be required to gain control of the situation post-disaster. As units are most likely to perform duties related to their “core competencies” as stated in CIMS, strategic and tactical direction must be conducted with this in mind.

The Fire Department will largely be in control of fire suppression, search and evacuation, and technical rescue. NYPD will be in charge of force protection, keeping order, and enforcing any emergency rules and regulations in effect. EMT's, paramedics and related individuals in the medical field will take control of patient care and victim tracking. DOT and Sanitation would be best utilized in clearing roads for ground transportation while DOB will inspect structures in priority order starting with bridges

and tunnels, moving onto buildings needed for immediate use (large areas for temporary shelter, hospitals), and then buildings utilized for quality-of-life matters (electric substations, water treatment facilities).

Public-private partnerships will also be necessary as the Port Authority (PA) and private airlines arrange for the restoration of air transport, telecommunication providers work to restore services and utility companies coordinate with first responders to safely mitigate emergencies and quickly restore needed services. All agencies and businesses expected to be utilized in the aftermath of a large earthquake should be included in various parts of the FDNY's planning and representatives invited to attend tabletop exercises.

C. LACK OF HELP FROM SURROUNDING JURISDICTIONS

In the immediate aftermath of the terrorist attacks of September 11, 2001, FDNY operations were supplemented by firefighting resources from neighboring jurisdictions. It was not uncommon to find volunteer fire companies from surrounding areas in NYC firehouses on that day, and the days that followed, answering calls. This was necessary as a number of the FDNY's fire apparatus were destroyed and a vast majority of the remaining companies deployed to lower Manhattan, leaving fire resources in the rest of the city quite scarce. Unfortunately, the same cannot be expected following an earthquake of significant magnitude occurring in or around NYC.

As an earthquake occurring in the northeast region of the U.S. is likely to affect a number of large cities due to the underlying geology of the East Coast, assistance from surrounding jurisdictions is likely to be minimal, if present at all. Professional and volunteer companies are likely to be inundated with calls in their own districts and rescue and fire suppression units from farther jurisdictions actually able to offer assistance will be challenged with logistical problems such as scattered debris and poor or unsafe road conditions in the vicinity of NYC. Assistance from unaffected departments located a considerable distance from NYC may be necessary, although the transportation of required heavy equipment (hoses, portable fire pumps and aerial or tower ladders) is

estimated to take substantially longer than transportation of associated personnel. Transporting trained personnel and limited equipment would be feasible by air; however, apparatus may only be able to arrive via ship or ferry, a timely process, as rail and road conditions are likely to be severely hampered.

Pre-planning for a moderate or severe earthquake should certainly take into account the time it will take for manpower, equipment and expertise to make its way into the city. Identifying resilient avenues of transportation and locations for resource management ahead of time will likely expedite the flow of aid to NYC in the aftermath of the quake.

D. RIOTS/APOCALYPTIC GROUPS

Interagency cooperation with the NYPD is essential for crowd control and security following a strong earthquake. A devastating quake may result in a variety of reactions such as looting and vigilantism to untrained civilians attempting to perform rescue work, putting themselves in danger and compounding the problem. Law enforcement will face many challenges in dealing with the public following an earthquake and should consider prioritizing public safety and force protection in preference to rescue work.

According to Daniel Kruger, a social and evolutionary psychologist at the University of Michigan's School of Public Health, "people may be taking food and supplies they need for survival, actions most people would find excusable given the circumstances."³⁰⁵ Mr. Kruger also goes on to state that "if people do take non-necessities, such as TVs, they're probably not thinking about right and wrong since these uncertain situations can lead to a breakdown of social norms."³⁰⁶ These people, as well as Emotionally Disturbed Persons (EDP), must be handled professionally using necessary force, while still recognizing the extreme pressures a natural disaster may impose on an

³⁰⁵ Rachael Rettner, "Post-Disaster Looting: Loose Morals or Survival Instincts?" Live Science (March 3, 2010), <http://www.livescience.com/6146-post-disaster-looting-loose-morals-survival-instincts.html>.

³⁰⁶ Ibid.

unsuspecting population. FDNY personnel must recognize the potential for irrational behavior following a black swan, while remaining focused on the rescue effort.

Another problem field units may encounter is terrorist/apocalyptic groups with malicious intentions. Following the events of September 11, 2001, anthrax spores sent through the mail complicated FDNY operations as the extensive rescue and recovery operations at the World Trade Center site, along with the influx of 911 calls regarding “strange white powders,” spread FDNY resources thin. Strategies including the activation of “Hammer Teams” to handle white-powder calls, which were successful post-September 11, may have to be implemented again. Terrorist organizations, especially apocalyptic groups, whether associated with mainstream religions or not, may take advantage of the chaos following an earthquake, especially a devastating low-frequency quake in a high-profile location like NYC. Agency leaders pre-planning for this disaster should keep this in mind and modify procedures accordingly.

As far as FDNY units are concerned, All Unit Circular (AUC) 138, an existing operational procedure for times of civil disobedience, may need to be activated.³⁰⁷ To improve response procedures, it is recommended that NYPD be included in tabletop exercises involving the earthquake scenario. The use of armed Fire Marshal’s for force protection out in the field is also a consideration. These trained members can ride along in Battalion vehicles and be used for security and force protection on the scene of critical operations. As successfully executed following the Christchurch, New Zealand quake, officers from jurisdictions not affected by the quake and incoming military personnel can be sworn in for emergency duty and supplement the NYPD in law enforcement duties.

E. TRANSPORTATION

Transportation post-disaster includes not only getting victims out of affected areas to medical facilities and temporary shelters, but also consists of getting appropriate

³⁰⁷ New York City Fire Department, “FDNY Manual All Unit Circular 138,” (June 1988).

rescue personnel, resources and supplies into and throughout NYC. All available modes of transportation will have to be utilized to the greatest extent possible although some will be more limited than others.

Ground transportation is important, but will be limited depending on the condition of roads and presence of debris. Due to the numerous interconnections to the ground and reliance on consistent power, it is anticipated use of the local train service, including the subway system, will be non-existent. Transportation via air is a possible solution with supplies and personnel expeditiously transported to the closest, unaffected airport and delivery of limited supplies and real-time surveys accomplished via small aircraft or helicopter. Ocean-going vessels are able to serve a variety of purposes such as transporting vast amounts of resources and providing medical facilities, although it is anticipated the response time of these vessels will be slow comparable to other forms of transportation.

As rescue turns into recovery, additional avenues of access and egress into a number of critical NYC areas will open up, improving operations. Until then, however, resilient methods of transportation must be planned for and contacts with associated agencies or businesses established accordingly.

F. TEMPORARY SHELTER AND RESOURCE DISTRIBUTION

According to a 1982 UN article, “disasters are not merely acts of God but are aggravated by human error and lack of foresight.”³⁰⁸ The UN study highlights principles that should be adhered to in preparing victim shelters following a disaster. In summary, these principles are listed below.³⁰⁹

1. Resources of survivors – The primary resource in post-disaster shelter.
Duplicating actions of survivors should be avoided.

308 “Shelter After Disaster: Guidelines for Assistance,” United Nations. (1982).
<http://reliefweb.int/sites/reliefweb.int/files/resources/E4FE896AFFF16709C1256CB10056558E-undro-shelter1-jul82.pdf>. 2.

309 “Shelter After Disaster: Guidelines for Assistance,” United Nations. (1982),
<http://reliefweb.int/sites/reliefweb.int/files/resources/E4FE896AFFF16709C1256CB10056558E-undro-shelter1-jul82.pdf>, 8–9.

2. Allocation of roles for existing groups – This should be undertaken by local authorities best qualified to decide who should do what, when and where.
3. Assessment of needs – Assessing short-term human needs is more important than assessing damage to houses and property.
4. Evacuation of survivors – Compulsory evacuation can retard recovery and cause resentment while voluntary evacuation can be a positive asset.
5. The role of emergency shelter – Understand the relevance of true emergency shelter.
6. Shelter strategies – The earlier reconstruction begins, the lower the social, economic and capital costs.
7. Contingency Planning (Preparedness) – This can help reduce distress and homelessness.
8. Reconstruction – An opportunity to introduce new building methods and regulations to reduce future hazards.
9. Relocation of settlements – This is rarely feasible except in the case of partial relocations within a city or town, which results from recognition of specific hazard areas.
10. Land use and land tenure – Take into account all aspects of land use and infrastructure planning.
11. Financing shelter – Utilizing grants is a short-term solution, however, it is more advantageous for the community to participate in the financing of their own permanent reconstruction.
12. Rising expectations – Temporary shelter frequently accelerates the desire for permanent, modern housing, well beyond reasonable expectations.
13. Accountability of donors to recipients of aid – The most effective relief and reconstruction policies result from the participation of survivors in determining and planning their own needs.
14. Guidelines for the local level – This should be formulated by qualified, local personnel in light of prevailing conditions.

The list above is a comprehensive guide to effective sheltering following a natural disaster and the FDNY need not be familiar with all principals. As primarily an immediate response agency, the role of the first responder will be to direct victims to appropriate shelters and respond to shelters for emergency purposes. Most important, is the pre-designation of emergency shelters within and around NYC and FDNY policy-makers must keep this in mind when planning for an earthquake. NYC has a number of structures that may be utilized for sheltering the thousands of evacuees to be expected.

Many buildings that have been designated as “fallout shelters” in the past should be considered as well as stadiums, arenas and public parks. Of course, all of these structures would need an expedited safety inspection performed by experienced DOB personnel prior to use. These facilities will also require law enforcement personnel for order and protection, as well as volunteers and supplies. The military will be able to assist in both of these crucial areas. Climate and weather conditions must be considered as well when exploring potential shelters. Should an earthquake occur in the middle of a harsh winter, outside areas such as stadiums and parks may not be suitable for victims. Similarly, victims will need adequate space and protection from heat during a hot summer.

Undoubtedly, a major earthquake will cause water pipes and sewer lines to be destroyed, undermining adjoining utilities, flooding certain areas, starting electrical fires and contaminating NYC’s clean water. Bottled water and rations will be required throughout shelters and medical facilities. Additionally, provisions must be made to provide necessities such as toiletries, portable showers and toilets, and both over-the-counter and prescription medications. Law enforcement personnel may be required to ensure the equitable distribution of these resources and the FDNY will have to prioritize response to both temporary shelters and resource distribution centers post-quake.

G. COMMUNICATION

The FDNY is strikingly resilient when it comes to intra-unit communications. FDNY members are provided with UHF Handie-talkies, spare batteries, and battery charges supplied by individual apparatus and firehouse generators at select locations. More problematic, however, is the 911 system. Even if landlines or dispatch offices are not damaged by the initial tremors, it is expected the 911 system will be overwhelmed with calls from distressed, panicked or trapped civilians. A total breakdown of communication should be anticipated and plans for breaking FDNY general response areas into sectors considered.

Worst-case scenarios will call for individual units, member teams or civilian volunteers to patrol areas for fires and other emergencies until a reliable “911” system

comes back online. Reliance on the armed forces and their military-grade communication equipment may have to be resorted to. Cell phone companies may be able to offer limited service to select users provided their own facilities are not damaged. Discussions with representatives of these companies and an analysis of the resiliency of their networks will be necessary. In addition, field-testing of military-grade communication equipment deserves consideration. Tabletop exercises should include creative alternatives to current vulnerable communication systems.

H. RECALL

As the communication systems of NYC are likely to be down in the immediate aftermath of the disaster, current methods of recalling first responders via phone call, text message or even local media could be ineffective. Additional options must be taken into consideration including back-up communication systems, radio, unaffected media outlets and even social media if possible. It should also be anticipated that many first responders will be dealing with their own concerns and family matters, including rescue operations in their own communities, within or outside NYC.

Responders living outside of the five boroughs may find it difficult to travel into the city and additional modes of transportation may be required. In any case, it can be anticipated that on-duty responders will be working for long periods of time and logistics commanders must keep this in mind when setting up resource and rehabilitation centers. Working closely with NYPD, access into the city should be initially reserved only for emergency responders, law enforcement and medical personnel. Civilians looking for loved ones, business owners and good-intentioned volunteers must be publically urged to steer clear of the limited access routes into the city. The use of media outlets will be crucial in transmitting this information as will be the efforts of the NYPD to allow emergency responders access while turning others away. In addition, it is recommended that all emergency personnel be advised to carry their official identification with them while responding in from home to be granted access to avenues of entry into the city. Prior knowledge, proper training or media outlets on the day of the event may be used to accomplish this.

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VI. RECOMMENDATIONS AND CONCLUSION

How can the FDNY prepare for a high risk, low frequency seismic event in NYC? The answer to this question depends on the unyielding commitment and dedication of the FDNY's senior management. Historical evidence, current data and ongoing research has proven that NYC is indeed prone to a moderate or severe earthquake and such an event will occur in the future. As is demonstrated time and time again, FDNY senior officers are undoubtedly resourceful in planning for the most severe and unlikely potential crises; and earthquakes should be no exception. Currently, the FDNY lacks a response strategy for an earthquake scenario in or around NYC. The intent of this thesis is not to form specific plans for all scenarios, but to alert the leadership of the FDNY to the potential of an earthquake striking NYC and entice these knowledgeable and experienced officers to factor in this possibility into their awareness and designated response plans for their own districts and areas of responsibility. The formation of an exclusive FDNY Response Plan for an earthquake scenario with emphasis placed on borough-wide response strategies is a necessary first step for preparing the FDNY for an earthquake. Ultimately, the recommendations provided after a thorough analysis of the case studies, coupled with the recognition of NYC's vulnerabilities and the potential challenges faced by the FDNY, will assist FDNY leaders in preparing for this potential threat.

Budgeting for such a low probability event would hardly be justifiable. Likewise, pursuing grants or other forms of economic aid for this black swan would be futile. Instead, pre-planning with the resources the FDNY already has is an effective option. Financial aid from the Federal Government, non-profit organizations (NPO) and empathetic civilians is likely to flow into NYC following a disastrous earthquake which would assist in the recovery. Public Awareness campaigns regarding a specific low frequency threat such as an earthquake are not worth undertaking however, as part of an overall safety campaign (fire, hurricanes, earthquakes), they may be beneficial.

The most practical solution for earthquake preparation in NYC is an effective pre-plan coupled with periodic table-top exercises. FDNY Borough Commanders can

perform a hazard analysis of the districts under their command utilizing knowledgeable staff and eager subordinates. This hazard assessment will be the foundation whereby FDNY leadership will discuss, and ultimately plan for, a potential earthquake scenario. The resultant strategies formed can be used in varying degrees depending on the severity of the quake. Whether it is an M 6 earthquake occurring hundreds of miles away that lightly shakes NYC's highest structures, or an M 6 with an epicenter in the city itself that destroys NYC's bridges and tunnels, having a plan will increase responder confidence, minimize casualties and allow citizens to resume normal activities far quicker than being caught off-guard during this black swan. Obviously the low frequency of earthquakes affecting NYC does not warrant unnecessary alarm, wasted resources and extensive measures. However, the high risk associated with such a potential event demands some action on the part of NYC's first responders. A well-thought-out strategic plan, coupled with the knowledge and experience of all of the FDNY's members, may just result in an effective, safe and world-renown response to an event that almost no one could anticipate.

The analysis of the earthquake hazard in NYC coupled with a review of current FDNY policies underscores the importance of preparing the FDNY for a major seismic event. To do so will require an implementation plan taking into account two crucial factors. The first is to utilize existing chain-of-command procedures to gather information regarding specific areas and threats in each of NYC's numerous communities. Local Battalion Chiefs can utilize information gathered from units under their command and identify specific hazard areas or useful areas (such as open areas and lakes or ponds). Higher-ranking Deputy Chiefs will then collate Battalion recommendations and endorse as necessary. After offering their professional opinion, this information will ultimately be distributed to the Borough Commander of each borough who will review the recommendations of Deputy and Battalion Chiefs, edit or add necessary information, and discuss the plan with the Chief of Operations, Chief of Department, Fire Commissioner and finally, a dedicated focus group.

The establishment of a dedicated focus group is the second factor in formulating an effective pre-plan for an earthquake in NYC. This group should consist of a variety of educated and experienced FDNY members of diverse backgrounds and of different ranks within the Department. The goals of this group will be to record and establish a preliminary IAP based on information retrieved from group meetings with the agency heads (high-ranking chiefs) of the FDNY. This group will also be responsible for contacting applicable agencies and organizations for emergency contact numbers and to keep them updated of specific goals related to FDNY earthquake preparedness, while establishing rapport for future inter-agency considerations. Finally, the focus group will organize table-top exercises and include FDNY decision-makers and planners, along with related agency and business leaders, in these exercises to test the FDNY's capabilities in an earthquake scenario. As lessons are learned and weaknesses revealed, the plan will be modified as necessary.

Based on the recommendations provided by an analysis of the aforementioned case studies, coupled with data relating to NYC's specific vulnerabilities, the focus group should begin formulating an earthquake response strategy with the following actions:

1. The focus group should establish contact with local military leaders to record emergency contact information and establish rapport.
2. Have FDNY Research & Development (R&D) solicit bids for temporary field hospitals that may be set up by EMS Command.
3. The focus group shall contact the United States Coast Guard (USCG) to identify accessible waterways in and around NYC. FDNY lawyers shall determine the legality of appropriately commandeering vessels in times of crisis as the focus group establishes rapport with local vessel operators to determine the most effective way of accomplishing this.
4. The focus group shall establish emergency contact information with individuals in charge of heliports and explore the feasibility of landing in different types of local terrain (open fields, waterways).
5. Have local Battalions recommend open areas, offering unimpeded access routes, for mustering of emergency responders.
6. The focus group shall analyze citywide reserves of food and water and establish a plan to distribute these reserves first to emergency responders and the sick/injured, and then to the general population.

7. The focus group shall contact the OEM to determine procedures for declaring a “state of emergency” and brainstorm adjusting these levels under certain conditions.
8. Use the chain-of command to identify “target hazard” buildings and areas as well as using existing “pre-incident guideline” (PG) structures, available on the FDNY Intranet, to analyze their vulnerability during an earthquake. Develop a city-wide strategy for a possible Indian Point nuclear facility disaster.
9. Include hospital staff in table-top exercises and have units identify specific local, hardened medical clinics for possible emergency treatment.
10. The focus group shall establish rapport with private companies, prioritizing energy and utility companies, and include these companies in table-top exercises.
11. Ensure points-of-contact are established with supervisors of gas, power, water, electric and other utilities, to ensure timely control and isolation of services. Explore the feasibility of expanding procedures for contact with Con Ed (Electric) Control Center and Substation Shift Managers to include gas, water and other utilities. Establish methods for secondary and tertiary means of communication should cell phone service be disrupted.
12. The focus group shall confer with NYC DOB and dispatchers to determine the possibility of establishing rapid-assessment teams to respond to pre-designated access points within the five boroughs in order to prioritize emergency resource allocation.
13. The focus group shall confer with NYC DOB to determine existing procedures of marking damaged buildings in an emergency, and if none, establish such procedures. FDNY operating procedures shall be adjusted with this in mind.
14. The focus group shall review international best practices for earthquake response and feasibility of using these procedures in NYC.
15. The focus group, through OEM, shall legally determine a lead agency for an earthquake response, while maintaining current policies of the Incident Command System and specific agency core competencies.
16. Utilize the chain-of-command to identify hardened structures that can serve as possible primary, secondary and tertiary command centers.
17. The focus group shall establish a comprehensive list of all FDNY facilities with working emergency generators and identify other public and private buildings with this level of resiliency.

18. The focus group shall establish a comprehensive list of all natural, dependable water sources for fire suppression and identify key problem areas in need of expedient water delivery in the event of an earthquake.
19. The focus group shall contact volunteer organizations and private corporations to include these crucial components of the overall response system in exercises, while offering them guidance and advice in their own emergency response policies.
20. FDNY lawyers shall evaluate the legality of establishing curfews as the focus groups work with NYPD counterparts to identify problem areas and establish a working relationship.
21. The focus group shall include the NYPD in table-top exercises and modify current FDNY/NYPD procedures to include operations during periods of disaster-related civil disobedience.
22. Utilize FDNY lawyers and the focus group, in consultation with the City Council and OEM, to discuss the possibility of increasing penalties for crimes during “states of emergency.”
23. Compare existing OEM stockpiled emergency supplies to what may be needed following an earthquake. Explore the feasibility of altering the amount and type of supplies and medicine for an “all hazards” approach. Determine the usefulness of current FDNY BIOPOD procedures in disseminating medicine and vaccines in the event of an earthquake.
24. Review current designated flood zones in NYC and compare these locations to areas expected to be flooded in the event of a tsunami. Analyze current evacuation plans for these zones and explore the possibility of managing this evacuation with little or no warning.

These implementations will require time and personnel. What they will not require, however, is a substantial amount of funding. Extensive Department-wide training and issuance of new equipment is not necessary. The only costs that the Department will incur is the utilization of a small number of individuals, which could be used for staffing out in the field, to spend their full time and energy as part of the focus group. This minimal amount of money can be obtained from the FDNY’s annual budget, thus preparing the FDNY for the high-risk, low probability earthquake without much political and media opposition.

Like the attacks of September 11, 2001, NYC is prone to nearly inconceivable existential threats. With proper training and education, however, knowledgeable and experienced emergency managers can formulate strategies to deal with potential problems following the next black swan. America's largest city should not be caught off-guard under any circumstances. A moderate to severe earthquake is a high risk, low frequency event. As previously stated, the August 10, 1884, M 5.2 quake with an epicenter in New York Harbor may occur once every 50 to 100 years, with a stronger M 6 quake potentially striking every 400 to 500 years. It is already well over 100 years and one can only guess when a potential M 6 quake will strike.³¹⁰ Because of the low frequency of this event in an average citizen's lifetime, it would be extremely difficult, if not impossible, to demand resources and economic aid for preparation. What can be done, however, is emulate successful preparatory efforts taken by other countries in order to have first responders perform efficiently and safely. Pre-planning and table-top exercises need to be conducted among the highest levels of emergency managers, anticipating challenges and reviewing options based on resources currently on hand. By doing so, NYC response agencies will save more lives and return the city to normalcy as quickly as possible.

³¹⁰ It is important to note here that this timetable does not actually increase the probability of the event as "50 to 100 years" is just an average. Dinicola, Karen. "The 100 Year Flood." <http://pubs.usgs.gov/fs/FS-229-96/>.

APPENDIX LESSONS LEARNED IN CASE STUDIES

Table 8. Recommendations Based on “Lessons Learned” in Case Studies.

Recommendation	Haiti	Chile	Japan	New Zealand	Loma Prieta
Plan for quick, efficient aid from local, military and international experts.	X	X		X	
Explore the possibility of setting up a temporary field hospital.				X	
Explore the possibility of utilizing open waterways for medical ocean vessels, military ships and boats distributing large amounts of resources. Also consider the feasibility of commandeering existing commercial vessels for emergency transportation and use.	X				
Explore the possibility of using local helicopters for survey and to bypass damaged roads.	X				
Pre-plan open, wide areas, with unimpeded access routes for mustering of emergency responders.		X			X
Plan for extensive, city-wide resource management such as distributed food & water.		X			
Review procedures for declaring a “state of emergency” early, when the need is evident.		X		X	
Evaluate special hazards city-wide (chemical plants, areas with extensive excavation work).		X	X		
Analyze the potential of using local, undamaged medical clinics for emergency treatment as well as trained medical professionals.				X	
Establish rapport with private companies (including infrastructure & utility companies) to ensure emergency resource allocation, transportation and infrastructure repair can be quickly accomplished.			X	X	X
Maintain points-of-contact are established with infrastructure supervisors to ensure the timely isolation of gas, power, water, electric and other utilities, when necessary. Ensure resilient means of communicating with these individuals.			X	X	
Establish a method whereby structural engineers can ensure a quick survey of designated access points (bridges, roads and tunnels) for use by emergency responders.				X	
Identify procedures to assess the integrity of damaged buildings and the use of easily-identifiable methods (numbers, letters, or colors) to assign hazard levels post-disaster.				X	
Follow international best practices for earthquake response.				X	
Pre-plan for a designated Lead Agency.				X	
Identify and pre-determine possible command centers (strong, resilient structures).				X	
Identify areas and buildings with back-up generators.				X	
Pre-plan additional dependable water sources for fire					X

Recommendation	Haiti	Chile	Japan	New Zealand	Loma Prieta
suppression.					
Contact Volunteer & Business organizations (and possibly include them in tabletop exercises.)			X		X
Evaluate the feasibility of establishing curfews.		X			
Discuss law enforcement options for force protection and review existing procedures.				X	
Brainstorm the possibility of increasing penalties for crimes during “states of emergency.”		X			
Plan to stockpile anticipated emergency supplies and medicine specific for an earthquake response.				X	
Plan for the possibility of a tsunami and its associated hazards should one strike NYC coastal areas concurrent with, or subsequent to, a large earthquake.			X		

Table 9. Hazard Scores of Each Borough.

Vulnerabilities	Manhattan	Bronx	Brooklyn	Queens	Staten Island
Population	3	2	5	4	1
Subway System	5	2	4	3	1
Electric	5	2	4	3	1
Steam	3	1	2	2	1
Water	2	2	2	2	1
Sewer	4	5	2	3	1
Gas	3	3	3	3	3
Pipelines	1	2	2	2	2
Bridges/Tunnels	5	3	4	2	4
Buildings	5	3	4	4	1
Communications	1	1	1	1	1
Special Projects	3	1	1	1	1

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